2023-2027 Wolf population forecasting report

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Summary

The FWP commission was directed by the 2021 Montana legislature (SB 314) to reduce wolf populations to a sustainable level that is not less than the number needed to support 15 breeding pairs. The legislation emphasized and expanded the commission's authority to implement additional hunting and trapping regulations to accomplish this, including extended seasons, increased bag limits, and expanded hunting and trapping options such as snares, night-hunting, and the use of bait. To support the commission's decision-making process, FWP Wildlife Research & Technical Services Bureau made projections of the impacts of 5 human-caused mortality scenarios (annual totals of 338, 507, 557, 657, and 757) on wolf population sizes. These human-caused mortality scenarios represent the recent 10-year annual mean of 57 depredation removals added to public harvest levels of 281 (the recent 5-year mean public harvest), 450, 500, 600, and 700. The latter 4 projected harvest levels represented increases from the recent 5-year mean public harvest of 281, consistent with the intent to reduce the statewide wolf population size. For example, a public harvest of 450 would be 202 more wolves than the 2022 license year and 169 more than the 2018-2022 average. The simulation scenarios are therefore intended to represent a range of elevated public harvest levels that may be possible with the liberalized regulations. In each simulation scenario, we held total human-caused mortalities constant each future year. We generated projections with simulations from a population growth model that used past estimates of statewide wolf population size and an index of human-caused mortality rate (harvest and depredation removals during Jan 1–Dec 31 year *t* / population estimate for Dec year *t-1*) to forecast population sizes 5 years into the future. This human-caused mortality rate is an index to facilitate forecasting based on the empirical relationship with estimated growth rates. Even with the below average public harvest rates of 2022 (harvest=248), statewide wolf population estimates declined slightly from the previous year. Forecasting results indicate that when combined with the 10-year mean (2013-2022) number of depredation removals, continued public harvest at the recent 5-year mean (2018-2022) would result in a stable to slightly declining statewide population while public harvest levels of 450, 500, 600, and 700 would result in population declines of increasing magnitude. If the latter 4 harvest levels were to continue for more than a year, wolf population size would approach levels that could not support 15 breeding pairs within the 5-year projection period in each case, and this would occur more rapidly at the higher projected harvest levels.

Methods

Annual wolf population sizes –

We used mid-winter (Dec) wolf population size estimates from an integrated patch occupancy model (iPOM) (Sells et al. 2022). With iPOM, an occupancy model estimates the extent of wolf distribution in Montana, and a territory model predicts territory sizes; together, these models predict the number of packs. A group size model predicts pack sizes. Total abundance estimates are derived by combining the estimated number of packs and pack sizes, while also accounting for lone and dispersing wolves. Further detail can be found in Sells et al. (2022) and the 2022 wolf annual report (Parks et al. 2023).

Modeling wolf population dynamics–

We used the mid-winter iPOM population estimates (Y_t, Dec of year *t*; Figure 1A,B) and their associated measures of uncertainty ($\sigma_{t_{observation}}$) as the input for a model of annual population dynamics which estimated the effect of the human-caused mortality rate index. Human-caused mortality (Jan 1 – Dec 31 of year *t*; Figure 1C) was estimated as mandatory reported hunter harvest and lethal removal of wolves involved in livestock depredation by USDA Wildlife Services and private landowners (under applicable Montana statute). For this analysis, a year is defined as the calendar year (Jan 1 – Dec 31) and harvest and lethal removal numbers will differ from the 2022 License Year. Our model took an empirical approach, modeling past annual growth rates (λ_t; Figure 1B) as a function of the annual index of human-caused mortality rate ($\mathrm{H}_t = human\ caused\ mortality_t\ /\ Y_{t-1}$; Figure 1D). This is similar to previous work by Gude et al. (2012), except here we use iPOM population estimates rather than minimum population counts, and our approach includes an observation model that accounts for uncertainty in the iPOM population estimates. It is important to note that that H_t should not be misconstrued as the actual percentage of the Dec *t*-1 population (Y_{t-1}) that is removed. Harvest and removals occur throughout the calendar year, which encompasses a birth pulse in early spring. Those young of the year are available for harvest in the 2nd half of the calendar year, thus the true percent of the Y_{t-1} removed is lower than H_t. Similarly, a dispersal pulse occurs in early winter with an unknown number of wolves entering and leaving the Montana population. The population model is as follows:

$$\lambda_t = Normal(\alpha + \beta_1 \times \mathrm{H}_t, \sigma_{process})$$

$$N_t = N_{t-1} \times \lambda_t$$

$$Y_t \sim Normal(N_t, \sigma_{t_{observation}})$$

where α is the regression intercept, β_1 is the slope of the relationship between annual human-caused mortality rate index and growth rate. N_t is the true, but unobserved population size, and $\sigma_{process}$ describes the variation in annual growth rates unaccounted for by the human-caused mortality rate index and driven by environmental and demographic stochasticity. While there may be some level of density dependent regulation in Montana's wolf populations, we were unable to estimate this effect because human-caused mortality and N are confounded in our 2007-2022 dataset (they both increase over the time period) and therefore these parameters were not separately identifiable in our model. Given our charge to forecast the effect of future human-caused mortality, we included that effect and not a density dependence effect. Therefore, our projections assume that human-caused mortality rate is the primary driver of population dynamics and do not account for declining recruitment associated with a saturated population, nor increases in wolf recruitment that may occur if the population is in fact reduced in the coming years.

We fit the model in a Bayesian statistical estimation framework using JAGS software (4.3.0; Plummer 2003) executed from R via the package jagsUI (Kellner 2019), a wrapper to the package rjags (Plummer 2019). The Bayesian framework simplifies the inclusion of uncertainty in past population estimates and appropriate propagation of uncertainty into future forecasts. We generated 3 chains with 500,000 iterations, a burn-in of 50,000, and a thinning rate of 10. We assessed convergence by ensuring Gelman-

Rubin convergence statistic for each parameter was <1.1 (Brooks and Gelman 1998) and that chains were well-mixed. Estimated parameters were given uninformative priors. Code for the model is given in appendix A.

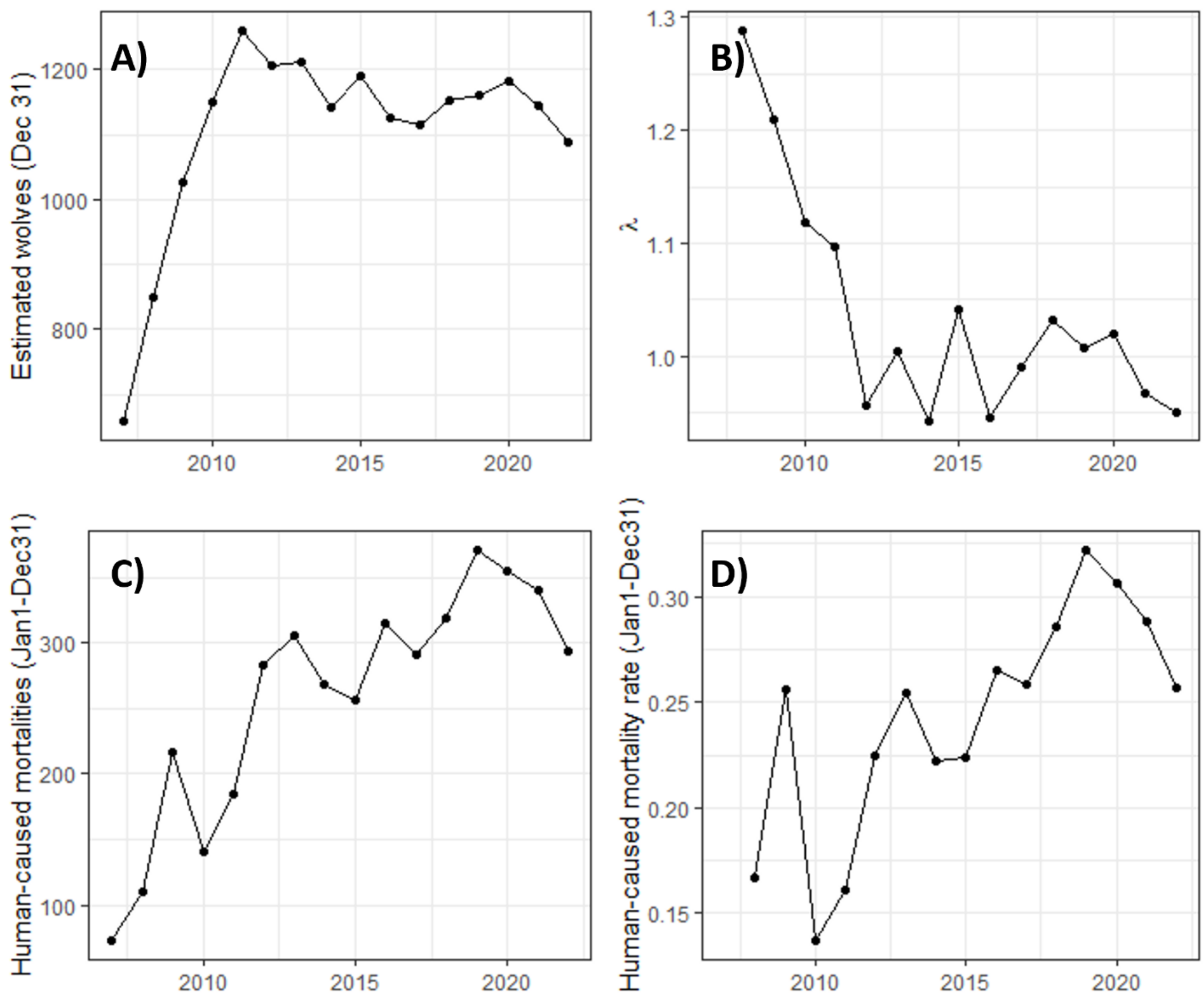

Figure 1. Statewide estimates for 2007-2022 of A) iPOM-estimated wolf population size for December each year, B) estimated wolf population growth rate, C) reported human-caused mortalities (between Jan 1–Dec 31), and D) estimated human-caused mortality rate index (H_t = human-caused mortalities$_t$ / iPOM wolves$_{t-1}$).

Results

The human-caused mortality rate index was negatively related to annual growth rates (Figure 2) as in previous studies (Gude et al. 2012). Our model estimated that a human-caused mortality rate index of approximately 27.5% would result in stable annual population growth (λ = 1.00; 90% credible interval = 0.957, 1.05). In studies from other locations with human-caused mortality, λ values ranging from 0.95–1.05 were observed when human-caused mortality rates ranged from 24–40% (Fuller et al. 2003). However, the human-caused mortality rates reported by Fuller et al. (2003) are not directly comparable to our index values. Fuller et al. (2003) reported the proportion of each population removed annually, whereas our estimate is based on the proportion of the previous population estimate harvested in the subsequent year, to facilitate forecasting, as described above.

The 2021 Montana legislature (SB 314) directed the FWP commission to reduce wolf populations to a sustainable level that is not less than the number needed to support 15 breeding pairs. The FWP commission changed numerous harvest regulations to promote higher harvests that were in effect during the 2nd half of the 2022 calendar year (i.e., during license year 2022 that spans fall 2022- spring 2023). For many reasons, including weather-related challenges and lower effort in many regions (Parks et al. 2023), the more liberal regulations in the 2022 license year did not result in higher harvest. The public harvest of wolves was below average for the 2022 calendar year (harvest = 248). Even with fewer public harvests, estimated wolf populations declined from the previous year.

All forecast scenarios resulted in predicted declines, though the predicted population trend under the recent 5-year mean (2018-2022) harvest scenario (harvest = 281), was only slightly declining during the 5-year forecast period. In all other scenarios there is a strong possibility that wolf populations would be extirpated or too low to support 15 breeding pairs by the end of the 5-year period if human-caused mortality levels remained stable (Figure 3). These predictions assume that the absolute levels of human-caused mortality would remain at the same high level for each simulated year regardless of population response, so this result was not surprising. Constant total harvest would lead to an exponentially increasing human-caused mortality rate as wolf numbers declined. Greater human-caused mortality rates would be increasingly difficult to achieve. Our scenarios do not represent harvest prescriptions or predictions of what the future harvest will be; rather they are intended to represent the possible consequences of continued public harvest at the recent 5-year mean and increases that may result from more liberal regulations enacted by the commission. If any of the elevated human-caused mortality levels could be achieved, harvest levels would likely need to be reduced after 1-3 years to prevent the population from decreasing below the level needed to support 15 breeding pairs, as set in state and federal law.

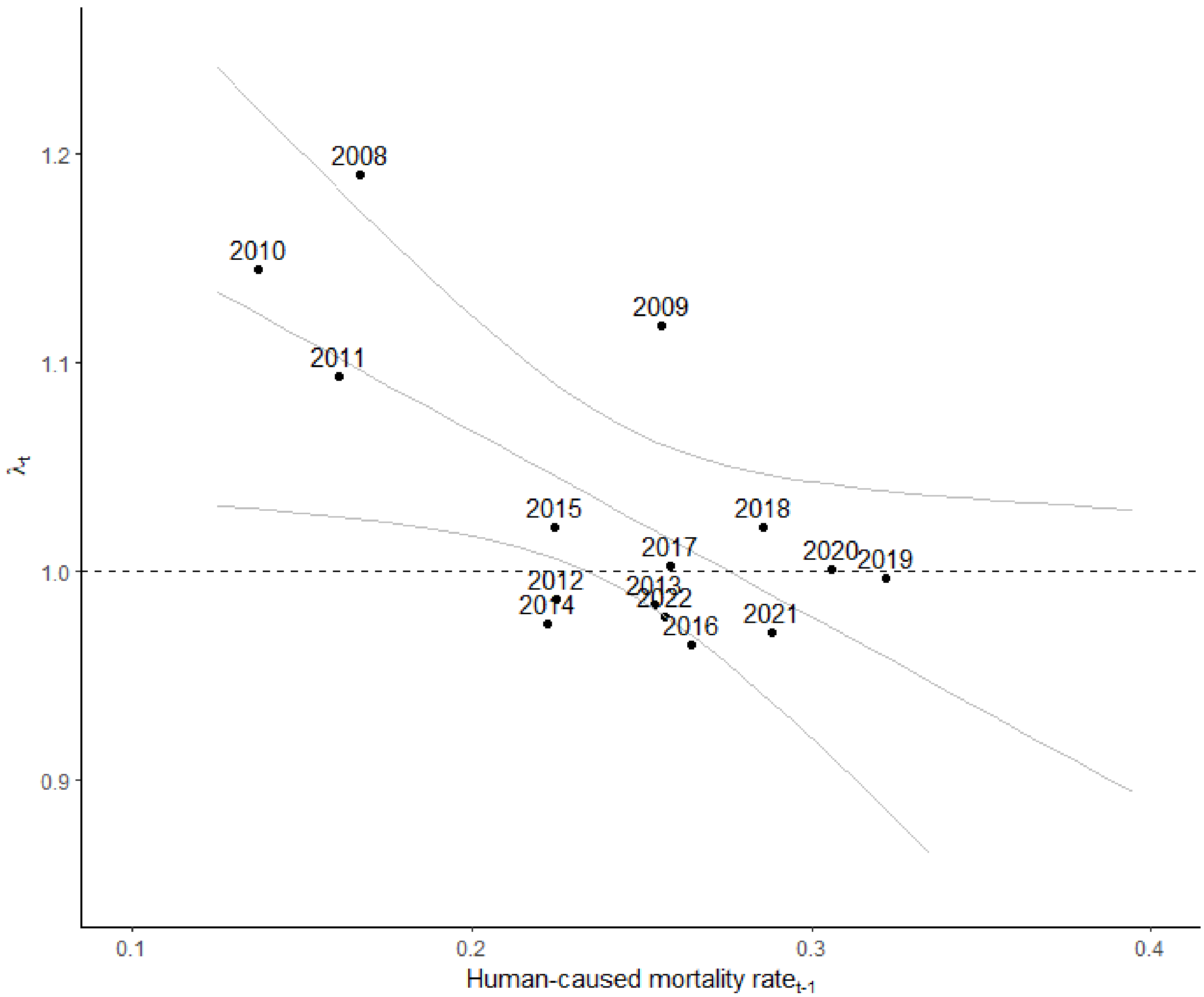

Figure 2. Estimated linear relationship and 90% credible intervals (grey lines) between annual wolf population growth rate (λ_t) and human-caused mortality rate (human-caused mortalities$_t$ / iPOM wolves$_{t-1}$). The human-caused mortality rate resulting in an expected stable population (λ= 1) is approximately 27.5%.

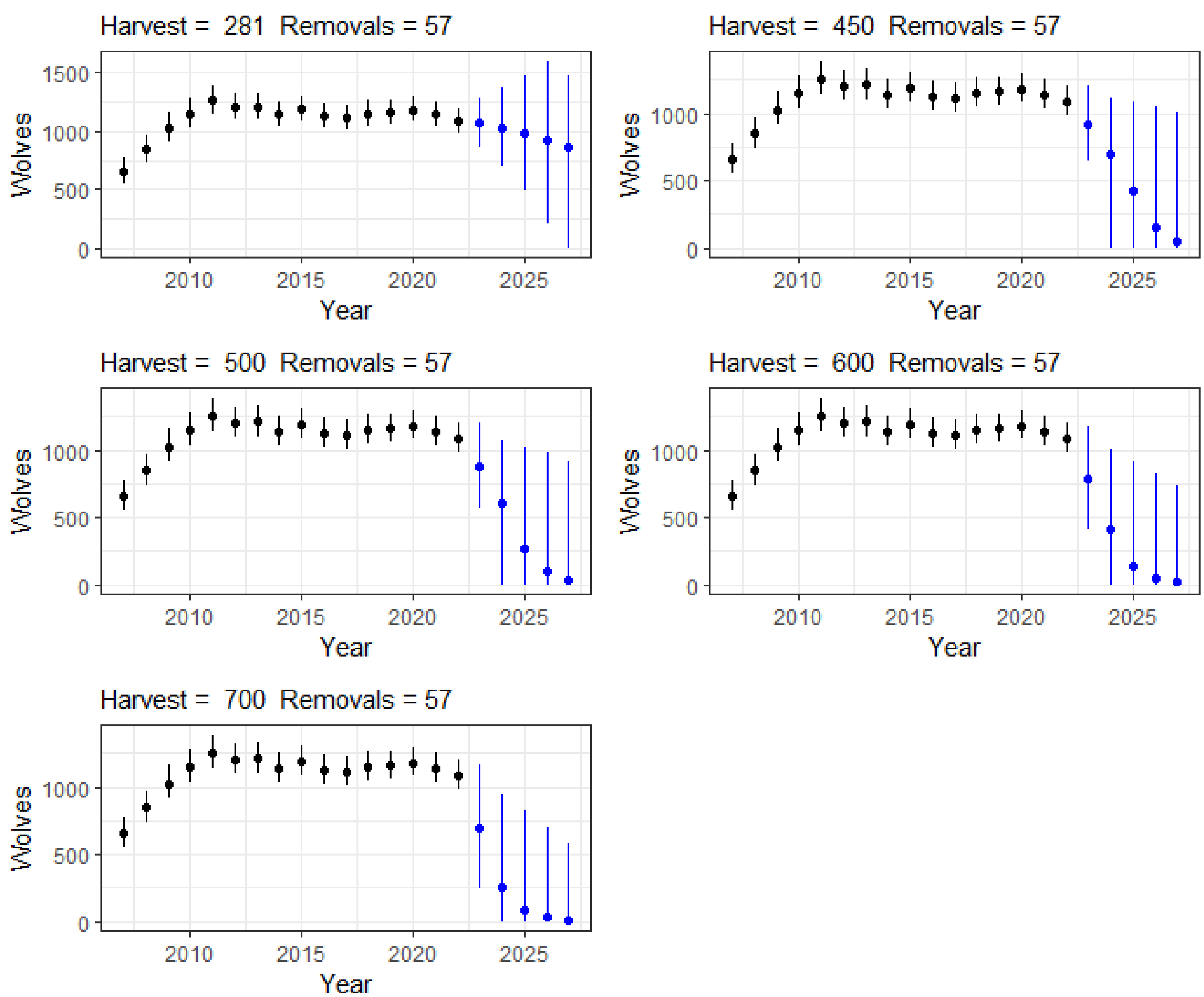

Figure 3. Wolf population model predictions under FWP commission requested human-caused harvest and removal scenarios. The 'Harvest=281" scenario represents the recent 5-year mean hunting and trapping harvest from 2018-2022. Black points and error bars are iPOM estimates with 95% credible intervals; blue points and error bars are simulation results for future years with 90% prediction intervals. Panel titles reflect the human-caused mortality scenario each year into the future.

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Appendix A. Model code

```
model {
    #population model
    for(t in 1:(nyears-1)){

        # Human-caused (HC) mortality rate index calculated in simulations to allow uncertainty
        # min() prevents harvest larger than N; 1 is added to N to prevent division by 0
        HC_mort_rate[t+1]<- min(HC_mortality[t+1], N.est[t]+1) / (N.est[t] +1)

        N.est[t+1]<- max(0, N.est[t] * lambda[t+1])

        # lambda distribution is truncated to prevent values <0 in simulations where regression
parameters would allow
        lambda[t+1] ~ dnorm(alpha+beta1*HC_mort_rate[t+1], sigma.proc^-2)T(0,)
    }


        sigma.proc ~ dunif(0,10)

  N.est[1] ~ dnorm(650, 57.14^-2) # 2007 iPOM estimate
  alpha ~ dnorm(0, 0.001) # intercept: predicted lambda when HC mortality rate index = 0
  beta1 ~ dnorm(0, 0.001) # slope: relationship between HC mortality rate index and lambda
```

```
  # # # #observation model - describes uncertainty in annual iPOM estimates
  for(t in 2:(nyears-5)){
      ipom[t]~ dnorm(N.est[t], se[t]^-2)
  }
}
```