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Computer Simulations of Baiting Efficacy for Raven Management Using DRC-1339 Egg Baits

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ABSTRACT: Raven populations that depredate livestock, damage agricultural crops, and injure endangered and threatened species, can be managed with egg baits containing the avicide DRC-1339 (3-chloro-*p*-toluidine). Estimating baiting efficacy is difficult, as DRC-1339 is a slow-acting toxicant. Efficacy estimation is further complicated by the feeding behavior of ravens at bait sites. To evaluate the efficacy of an egg baiting operation, we developed a computer simulation to predict bait consumption by ravens, incorporating a DRC-1339 degradation module to predict DRC-1339 bait concentration at the time of consumption and an effects module to predict the mortality associated with the resulting DRC-1339 dose. Details of the simulation will be presented in the context of predicting baiting efficacy using egg baits in different climatic environments. These preliminary results provide the basis for designing field studies that can be used to improve and validate the model.

KEY WORDS: avicide, *Corvus corax*, CPTH, DRC-1339, egg bait, model, raven

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INTRODUCTION

The avicide DRC-1339 (3-chloro-*p*-toluidine) is used by USDA APHIS Wildlife Services to manage livestock depredation by corvids under a Section 3 registration with the U.S. Environmental Protection Agency. It is applied in an egg or meat bait following prebaiting at the site. It is a slow-acting toxicant with high specificity for birds. Establishing efficacy is difficult, as it is rarely possible to recover a carcass following baiting. Efficacy estimation is further complicated by the uncertainties associated with the feeding behavior of corvids.

To facilitate improvements in efficacy estimation, a bioenergetics model was developed to predict the caloric requirement for corvids for any geographic location in the contiguous United States, and this daily caloric requirement is then used to estimate bait consumption. This model is derived from the bioenergetics model we developed for feedlots for estimating bait consumption using discrete bait pellets (Homan et al. 2005). This version of the model focuses exclusively on the use of egg baits as they are commonly used to minimize raven (*Corvus corax*) depredation on livestock (Larsen and Dietrich 1970) or to protect endangered wildlife (Spencer 2002, Coates et al. 2007).

METHODS

Our bioenergetics model uses an energy flux approach to calculate caloric requirement of a raven based on the difference between body temperature and an environmental temperature that corresponds to an ideal black body radiating at a temperature that would result from all the energy inputs in the bird's environment (Campbell 1977, Homan et al. 2005). The energy budget equation for a bird is:

$$M-\lambda E = \frac{\rho cp(T_b-T_e)}{r_{Hb} + r_e}$$

where M is the metabolic energy requirement of the bird, λE is the water vapor flux from the bird, ρcp is the specific heat capacity of air, T_b is the temperature of the bird, T_e is the environmental temperature, and $r_{Hb} + r_e$ is the total resistance to energy transfer between the bird and the surrounding environment. The model uses an hourly time step to calculate the environmental energy inputs that result in the value calculated for T_e. These are summed over a 24-hour interval to provide an estimate of the caloric requirement the bird must meet to offset the energy lost to its surroundings. Lethal take is estimated in the model, based on assumptions regarding the percentage of the daily caloric requirement a bird is acquiring while feeding on egg, and the probability that the bird has ingested a lethal dose with the LD_{50} = 13 mg/kg (Johnston et al. 2005, Eisemann et al. 2003, Larsen and Dietrich 1970). Each egg is assumed to contain 20 mg of DRC-1339. The dose in the egg is allowed to decrease at a fixed rate reflecting the high affinity of the DRC-1339 for the bait matrix, resulting in a decrease in effective dose.

We evaluated the model estimates for lethal take resulting from bait consumption assuming four feeding scenarios. The first was that each bird was limited to a single egg bait; in the second, each bird could consume up to two egg baits. In the third scenario, each bird could consume one egg, but 20% of the birds in the population could cache additional eggs up to their daily caloric requirement. In the final scenario, each bird could cache eggs up to their total daily caloric requirement. In all four scenarios, there is an assumption that a bird consumes all or part of the eggs within a 24-hour period. We investigated the effect of climate on estimating lethal take by using monthly summary climatic data for the month of April 2007 for locations in Arizona, Idaho, Nevada, Utah, and Wyoming (data obtained from the National Weather Service). These states were selected to provide a thermal range across the interior of the contiguous United States going from north to south.

The model was written in Visual Basic and runs as a macro in Microsoft Excel. The model inputs required are: daily minimum and maximum air temperature, the month of the year, the number of egg baits applied, the number of baits recovered at the end of the baiting operation, the number of eggs estimated to be required for effective control (1 or 2), the percentage of birds in the population caching eggs, wind speed, and percent cloud cover. For these simulations, 100 treated eggs were applied and 6 eggs bait were recovered at the end of the operation. The four feeding scenarios investigated were: 1 egg/bird, 2 eggs/bird, 1 egg/bird with 20% of the population caching eggs, and 1 egg/bird with all birds in the population caching eggs. There were no cloud inputs providing the bird with the maximum solar input during the baiting simulation. The daily minimum and maximum temperatures used for the five states are presented in Table 1. Fifty simulations were run for each baiting scenario at each location, and the mean and standard deviation for model estimates of efficacy were calculated for each state. We define efficacy as the raven take among birds that consumed treated eggs. An iteration of the model consists of calculating the energy requirement for a single bird, the number of eggs that bird will consume, the resulting dose, and the efficacy of that dose. In the scenario where a specified number of eggs are consumed, the amount of each egg consumed was estimated using a randomization procedure. In the cache scenarios, for each bird, the number of eggs cached as well as the amount of each egg consumed was generated using a randomization procedure. Model estimates across states were compared using a one-way ANOVA (R, Source: http://CRAN.R-project.org).

RESULTS

Air temperature is a major driver for calculating the energy flux between a bird and its environment. The equation for calculating T_e is:

$$T_e = T_a + r_e(R_{abs} - \sigma\varepsilon T_a^4)/\rho cp$$

where T_e is the equivalent environmental temperature, T_a is air temperature, ρcp is the specific heat capacity of air, r_e is a resistance term, ε is the surface emissivity, and σ is the Stephan-Boltzman constant. The relationship between air temperature and the magnitude of the mean caloric requirement for a population of birds is depicted in Figure 1. The average energy requirement for a population of birds is significantly different across the 5 states (ANOVA: DF(4,245), F = 11467, P>F = 2.2×10^{-16}).

The One Egg Bait per Bird Scenario

The feeding scenario assumptions interacted with climate/location to provide different estimates of bait efficacy. Figure 2 depicts the average number of mortalities associated with a 1 egg/bird baiting scenario. In all the locations, 94 birds ate some portion of an egg, because the scenario specified 1 egg per bird with 100 eggs available, and 6 eggs recovered. The values are the average estimates of efficacy plus 1 standard deviation for 50 model simulations per state. The estimates for mortality are not significantly different across the states (ANOVA: DF(4,245), F = 1.19, P>F = 0.31). On a relative percentage basis, a 1 egg/bird scenario results in a prediction of controlling 37% of the birds that consume bait.

Table 1. Daily temperature ranges by state.

State	Minimum Temperature (ºF)	Maximum Temperature (ºF)
AZ	58	84
ID	40	63
NV	60	80
UT	42	63
WY	33	63

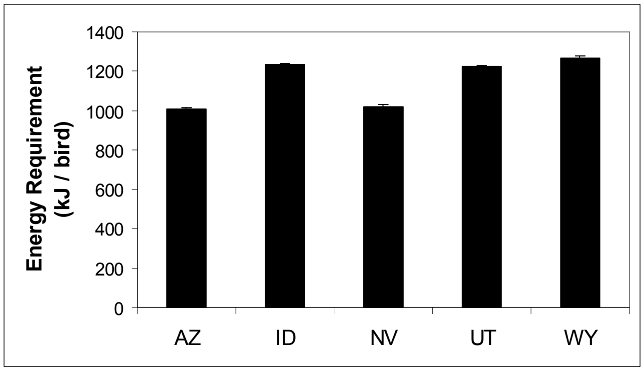

Figure 1. The mean daily energy requirement for ravens by state. Error bars are +1 standard deviation.

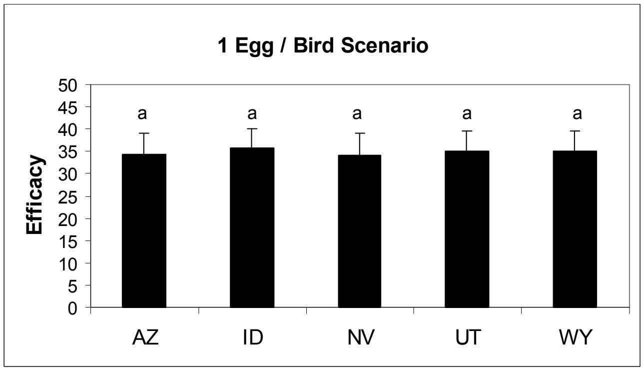

Figure 2. Estimates of bait efficacy when ravens consume up to one egg by state. Error bars are plus 1 standard deviation. Values identified with the same letter are not significantly different using the Tukey HSD procedure (α = 0.05).

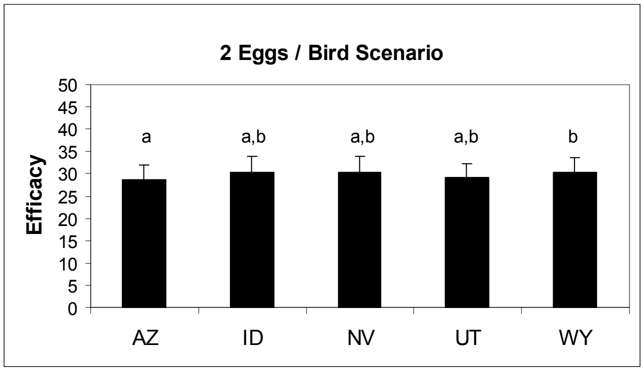

Figure 3. Estimates for bait efficacy when raven bait consumption is limited to a maximum of two eggs per bird, by state. Error bars are plus 1 standard deviation. Values identified with the same letter are not significantly different using the Tukey HSD procedure (α = 0.05).

The Two Egg Baits per Bird Scenario

The efficacy for the 2 eggs/bird scenario is depicted in Figure 3. In all the locations, 47 birds ate some portion of the 2 eggs, because the scenario specified 2 eggs per bird with the application of 100 eggs and 6 eggs recovered after baiting. The values plotted are the average estimates of efficacy plus 1 standard deviation for 50 model simulations per state. The estimates for mortality are significantly different across the states (ANOVA: DF(4,245), F = 3.48, P>F = 0.0086). The mortality estimates are different between AZ and WY but are not different for the remaining three states, using the Tukey HSD procedure with $\alpha = 0.05$. The 2 eggs/bird scenario results in the prediction for the successful take of approximately 64% of the birds that consume bait across all locations.

The One Egg per Bird Scenario with 20% of the Population Caching Eggs

Allowing birds to cache eggs as part of their feeding behavior changes the estimates of bait consumption significantly. The numbers of birds feeding on egg baits are significantly different by state across the this scenario, with a range of 70-80 birds feeding on the egg baits (ANOVA: DF(4,245), F = 12.59, P>F = 2.5×10^{-9}). The model predictions for the efficacy of the baiting in the scenario where up to 20% of the birds cache eggs are depicted in Figure 4 and are not significantly different across the five states (ANOVA: DF(4,245), F = 1.04, P>F = 0.39). In this scenario, the take is approximately 50% of the baited birds.

The One Egg per Bird Scenario with All Birds Potentially Caching Eggs

In this scenario, where all the birds potentially cache eggs the number of birds feeding on egg baits ranges from 40-50 (ANOVA: DF(4,245), F = 100.42, P>F = 2.2×10^{-16}). The efficacy of the baiting is significantly different across the five states and is depicted in Figure 5 (ANOVA: DF(4,245), F = 12.47, P>F = 3.0×10^{-9}). The mortality estimates are different between the two warmer states (AZ, NV) and the other three cooler states (ID, UT, WY) using the Tukey HSD procedure with $\alpha = 0.05$. Take in this scenario corresponded to approximately 71% of the baited birds, across the states. In this scenario, the model predicts that the birds are likely to consume the most bait and acquire the largest lethal dose.

A 50-g egg contains approximately 250 kJ of energy. For all of the scenarios we explored, a bird would need to cache 4 or more eggs to meet its total daily energy requirement. The model simulations for caching egg behavior ranged on average from 2.3 eggs per bird to 2.6 eggs per bird across the 5 states. In cooler states, the birds tended to cache a total of 3 eggs compared to warmer states where the birds tended to cache a total of 2 eggs for consumption.

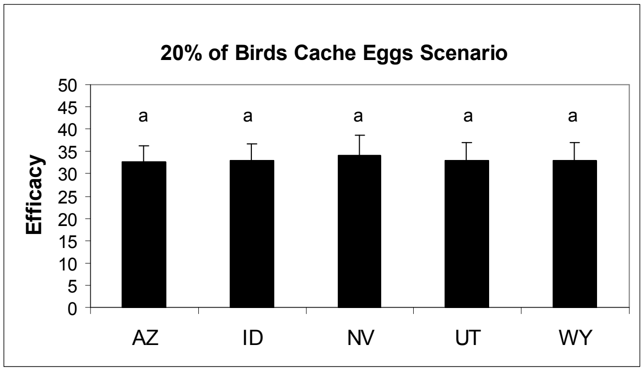

Figure 4. Estimates the bird population when raven bait consumption allows for the entire population to cache eggs, by state. Error bars are plus 1 standard deviation. Values identified with the same letter are not significantly different using the Tukey HSD procedure (α = 0.05).

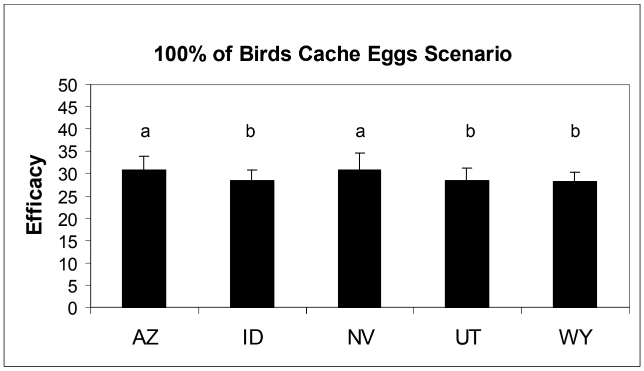

Figure 5. Estimates for bait efficacy when raven bait consumption allows for the entire population to cache eggs, by state. Error bars are plus 1 standard deviation. Values identified with the same letter are not significantly different using the Tukey HSD procedure (α = 0.05).

DISCUSSION

There are three general approaches for accounting for baiting efficacy of DRC-1339 egg baits in use by USDA APHIS WS Operations at the state level. These include the one DRC-1339 treated egg per bird estimate, the two DRC-1339 treated eggs per bird estimate, and the use of a difference method where birds are counted pre- and post-baiting. The development of this model is an effort to provide an alternative to estimate efficacy based on bird feeding behavior at the bait site and the resulting dose consumed. The model uses a random number generator to estimate consumption for any bird within the limits of the caloric requirement of the bird. This is done because of the lack of data that adequately describes the feeding behavior of ravens consuming egg baits. There are anecdotal reports that ravens will eat only the egg white or egg yolk. There are also reports that ravens will cache the eggs for consumption at a later date. Field studies conducted to address these issues and provide definitive data on the amount and portions of eggs consumed, as well as the effect of caching on consumption, would allow for better estimates of efficacy in the model. Other population metrics, such as age distribution and gender distribution of ravens consuming the bait, could be incorporated into the model if appropriate field data were collected and made available for use.

The distribution of the dose of DRC-1339 in the egg is another area worth evaluating. The model presently assumes a uniform distribution of the dose throughout the egg, even though the dose is applied primarily to the yolk. This could be combined with a storage stability study, as baits are commonly prepared in large batches and held until used. This data coupled with the previously mentioned feeding studies would greatly improve the estimate of dose consumed by a bird.

CONCLUSIONS

Simulations of baiting ravens with DRC-1339 provide an efficient means of estimating consumption of a lethal dose by a bird. The model's estimates of bait consumption reflect the impact of climate on the daily caloric requirements of the birds and the interaction of feeding behavior attributed to the bird populations. The model provides the basis for developing a useful tool, to be used in the management of nuisance populations of ravens using lethal control with DRC-1339. Additional scenarios could be developed and evaluated based upon supplemental field studies.

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