APPENDIX B

EXPERT ELICITATION METHODS AND RESULTS

Expert opinion served two critical and distinct roles in this modeling project. The first role was provided by a group of experts who advised the authors on all aspects of model development from initial concepts to the final simulations. The second role for expert judgment was providing quantitative estimates for specific model parameters where data from empirical research are limited or absent. We elicited current beliefs about parameter values from two sets of experts – a group of four eagle biologists, and a group of four veterinary scientists knowledgeable about lead poisoning and raptors.

The stages of model development were: (1) expert panel selection; (2) preliminary conceptual model development; (3) in-depth literature review; (4) conceptual model revision and preliminary parameter values selection; (5) deterministic spreadsheet model; (6) expert review and discussion (webinar); (7) stochastic spreadsheet model prototype; (8) expert review and discussion (webinar); (9) model revision, expansion and coding in Matlab; (10) formal elicitation of expert judgments for select parameter values; (11) prototype simulations and sensitivity analysis; (12) expert review and discussion (webinar); (13) repeat formal elicitation to update parameter values (note: steps 11-13 were completed twice, for total of three formal elicitation rounds); (14) final runs and sensitivity analysis; (15) final reviews.

Process for selecting experts

We took care to identify the purpose and specific roles for expert judgment in the model development process, and hence the particular areas of expertise and capabilities we needed for the expert team. Our goal was to work with a small group of experts who were not only deeply knowledgeable of relevant topics, but also effective communicators and willing contributors (e.g., combining content knowledge with ability to extrapolate to new contexts and ability to transfer knowledge; Burgman et al. 2011, McBride and Burgman 2012, Drescher et al. 2013). As a group, the panel needed to provide expertise in eagle behavior, ecology, and management; quantitative skills and modeling; regulatory requirements and mitigation planning; and field conditions in different regions of the Western U.S. Given these goals, we drafted lists of potential participants for our initial model design workshop in 2012 by considering (1) scientific qualifications, including past and current research, publications, and involvement with scientific analysis for eagle conservation or mitigation planning; and (2) professional reputations (from word-of-mouth networking and past experience of American Wind Wildlife Institute (AWWI) staff as most candidates had attended prior workshops on eagle conservation.[1] The invitation process was conducted and supported by AWWI. After the workshop, expert participation continued to evolve through the model development stages.

As we honed our focus to lead poisoning and Wyoming examples we consulted scientists with additional topical expertise, in particular bringing wildlife veterinarians with expertise in raptor lead poisoning and raptor biologists from the Northern Rockies to the group. A few experts stopped participating for lack of time or interest as the modeling advanced. In total, eight experts attended our August 2012 workshop, and another eight participated in one or more online webinars, reviewed modeling results and draft documents, and gave verbal suggestions to the

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[1] November 2011 Eagle Workshop in Denver, CO [AWWI]; September 2010 North American Golden Eagle Science Meeting in Ft. Collins, CO [USFWS]; March 2010 National Golden Eagle Colloquium in Carlsbad, CA [USFWS].

authors; of the 16 total, eight provided model parameter value estimates in formal elicitations (Table B1).

Conceptual to prototype model development

At the first workshop the first author led the expert panel through exercises to describe and draw a conceptual model of how ingesting lead ammunition fragments poisons Golden Eagles and how abatement strategies may reduce ingestion rates. Engaging experts in conceptual model development is largely a subjective process (Burgman 2005, Marcot et al. 2006), however, we employed best practices similar to those in formal parameter elicitation (e.g., Martin et al. 2012, McBride and Burgman 2012, Drescher et al. 2013) to help maximize critical thinking and information sharing, while minimizing biases such as anchoring and 'group think.' Sub-groups of 2-3 experts worked independently to draw initial 'box-and-arrow' diagrams depicting their understanding of cause and effect relationships, which the full group then discussed and edited together into a consensus diagram. The goal is to disaggregate the contributory factors in a complex ecological web to the level of resolution that is best understood by the experts (matches their expertise), is tractable for computational modeling, and supports future monitoring (Burgman 2005).

We converted the experts' diagram into a simple Bayes net version of the conceptual model (run in Netica, version 4.09, Norsys Systems Corp.) to facilitate further discussion of quantitative relationships. After the workshop, we reworked experts' causal model into a spreadsheet for calculating model outcomes and shared this first prototype with the experts by webinar followed by discussion and further revisions. This iterative build-review-revise process was repeated with the addition of stochastic parameters and more example runs over a couple months, before we settled on all the functional relationships to include in a fully computational model to be programmed in Matlab. The causal diagram depicted in Appendix C illustrates the key components of the final, computational model.

During early model development we also prepared a literature summary on eagles and lead poisoning for the experts to read as background information (Appendix A). Drawing from the literature summary and the preliminary spreadsheet analysis, we developed parameter values to use in the prototype simulations. We drew some of these values directly from data cited in appropriate literature (e.g., recovery rate for big game shot by hunters and daily decay rate for blood lead), and based others on the experts' recommendations, which were informed in turn by professional experiences and relevant literature (e.g., minimum lag time between gut pile scavenge events). For three parameters, however, we needed to elicit expert judgments more formally to develop functional distributions for the model's critical cause-effect relationships where we lacked empirical data.

Elicitation of model parameter values

We elicited or 'encoded' judgments for the model parameter 'eagle scavenging rate' from four of the experts who are highly experienced in Golden Eagle behavior (excluding the USFWS experts, who were not available for this part of the exercise), and for the two parameters addressing lead toxicity (blood lead level increase per scavenge and mortality per maximum blood lead level) from four experts in lead poisoning in raptors. Preparation steps to motivate and prepare the experts (McBride and Burgman 2012) included sharing and discussing summaries of relevant information, reiterating the purpose of the project and expected applications for the model (and hence, what the project and model were not attempting to address), seeking and recording definitions of terms and applicable quantitative units to be used in the analysis, clarifying assumptions, and agreeing to language for each elicitation question. Although we did not conduct separate 'dry runs' to practice elicitation with the experts, we revised the questions, definitions, and assumptions 'on the fly' during the first elicitation round as the experts or analysts felt it was needed and useful. For the remote elicitations, we sometimes included variant forms of some questions to determine which version was most suitable, and also asked some additional questions to get insights for the model development; we do not report all these details in this appendix. The first elicitation was completed during the workshop; all subsequent rounds (including all elicitation for the toxicology questions) occurred remotely. We employed a modified Delphi approach to the elicitation (Runge et al. 2011), first eliciting independent responses followed with tightly facilitated group discussions.

Each elicitation consisted of experts answering questions about how a parameter responds to specified predictor variable values by filling in tables in a spreadsheet (examples of elicitation instructions and questions in Figs. B1 to B4). Our question format largely followed Speirs-Bridge et al.'s (2010) four-point elicitation method in asking for the (1) lowest reasonable estimate, (2) highest reasonable estimate, (3) and most likely estimate for each value of interest, followed by (4) the expert's degree of confidence (from 50-100%) that the values for each parameter were within the lowest-highest range they provided. We elicited the estimates for scavenging rate associated with specific levels of eagle and gut pile densities, and for mortality rates associated with maximum blood lead concentrations. For lead consumption, the question took two forms: we asked for the "average" blood lead increase per scavenge on a gut pile that contains lead fragments (four-point method), then for a discrete probability distribution for the incremental increase in blood lead per gut pile scavenged. Thus while all questions asked directly for the parameter values of interest including the probability estimates, we also provided alternative wording in the questionnaires and in oral directions that encouraged the experts to think about probabilities as natural frequencies or proportions of events they could envision from their experiences (Burgman 2005, McBride and Burgman 2012).

We compiled all responses and comments (without attribution) in tables for each question, shared the results with the experts, and facilitated a discussion about the responses. For remote elicitation, we distributed the responses by email and discussed the responses by webinar and conference call. Following discussion we allowed each expert to update their responses as desired, usually by follow-up emails, after modifying any assumptions and questions as agreed upon by each team. We repeated this iterative cycle of response-review-revise until the experts stated they were satisfied that the elicited values represent the best available beliefs about the defined relationships. Final elicitation responses are illustrated in Figs. B5 to B7.

Developing parameter distributions from elicited beliefs

We developed distributions for the three elicited parameters by looking at the patterns among the elicited values and subjectively drawing curves over plots of the experts' point estimates. These functional shapes connect the discrete expert estimates to underlying ecological processes and theory (Burgman 2005). We used a Type II saturating curve for scavenging (later revised to Type III shape), a Cauchy function for the lead exposure curve, and a Michelis-Menton curve for the exposure-related mortality rates (for details, see Appendix C), assigning parameter values to those functions to produce curves that best matched plots of elicited values (with concurrence from the experts). Thus, the functions used in the model are subjective, “smoothed” representations for a range of expert beliefs.

Initially we ran the model deterministically with various sets of lowest and highest values to illustrate effects of these beliefs for the experts. In our first stochastic model prototype we drew two curves to broadly contain the low and high values among the experts’ most likely estimates and ran the model drawing stochastically from within those ranges. The variation among responses represents epistemic or scientific uncertainty about the ‘true’ functional relationships (Kuhnert 2010, Runge et al. 2011). We did not attempt to incorporate the additional uncertainty expressed in the expert’s individual confidence ranges in the model (e.g., by using the lowest and highest reasonable estimates adjusted for expressed confidence, or “derived credible intervals,” which requires assumptions about underlying distributions; see Speirs-Bridge et al. 2010).

Updating parameter values for final simulations

Prototype simulations provided insight about how the multiple contributory factors lead to total mortality rates, interacting in ways too complex to foresee intuitively. The experience of seeing simulation results allowed experts to update their beliefs about the model parameters and helped improve our representation of those beliefs. Since the first prototype simulations produced total mortality estimates exceeding what we thought was reasonable (e.g., >6-7%/yr maximum), we made adjustments to improve the shape or fit of our smoothed curves and address missing elements.

For scavenging rate, we omitted one expert's markedly high 'outlier' values and shifted from a clearly Type II to slightly Type III functional response based on expert suggestions (see Fig. B8). For probability of lead exposure per scavenge, we realized the expert's estimates had not taken into account the proportion of gut piles that did not contain any lead, which may be 10% (Hunt et al. 2006) or greater. Thus, lead exposure probability is a bimodal function, with modes at zero exposure and the mode E in the Cauchy distribution. In revising the model, we added the percentage of gut piles with no lead fragments as a separate parameter, and applied the Cauchy distribution only to the remaining proportion of gut piles that would contain some lead fragments. In addition, eagles typically regurgitate bullet fragments with other indigestible materials. Although pellets are usually cast at least 12 hours after ingestion (e.g., the morning following a meal) by which time some lead has eroded and been absorbed into the blood (Duke et al. 1975, Pattee et al. 1981), some portion of gut piles containing lead will still result in no increase in blood lead, as the eagle could regurgitate the lead fragments before the lead erodes and enters the bloodstream. That probability is accounted for in the Cauchy distribution if the mode exposure (E_{mode}) is not too high. Following prototype review, some of our experts realized they had not taken this small probability of no blood lead increase due to regurgitation into account during the parameter elicitation, thus we shifted the E_{mode} downward for the final modeling (see Fig. B9).

In preliminary model runs we determined that varying E_{max} from 200 to 1000 $\mu g/dL$ had almost no effect on overall mortality rates because these 'high end' lead concentrations have relatively low probability; thus, for remaining model runs we fixed E_{max} at 1000 $\mu g/dL$ and variation in potential lead exposure extends to the highest level expressed by any of the experts. Finally, for mortality rate we also omitted one high 'outlier' (see Fig. B10).

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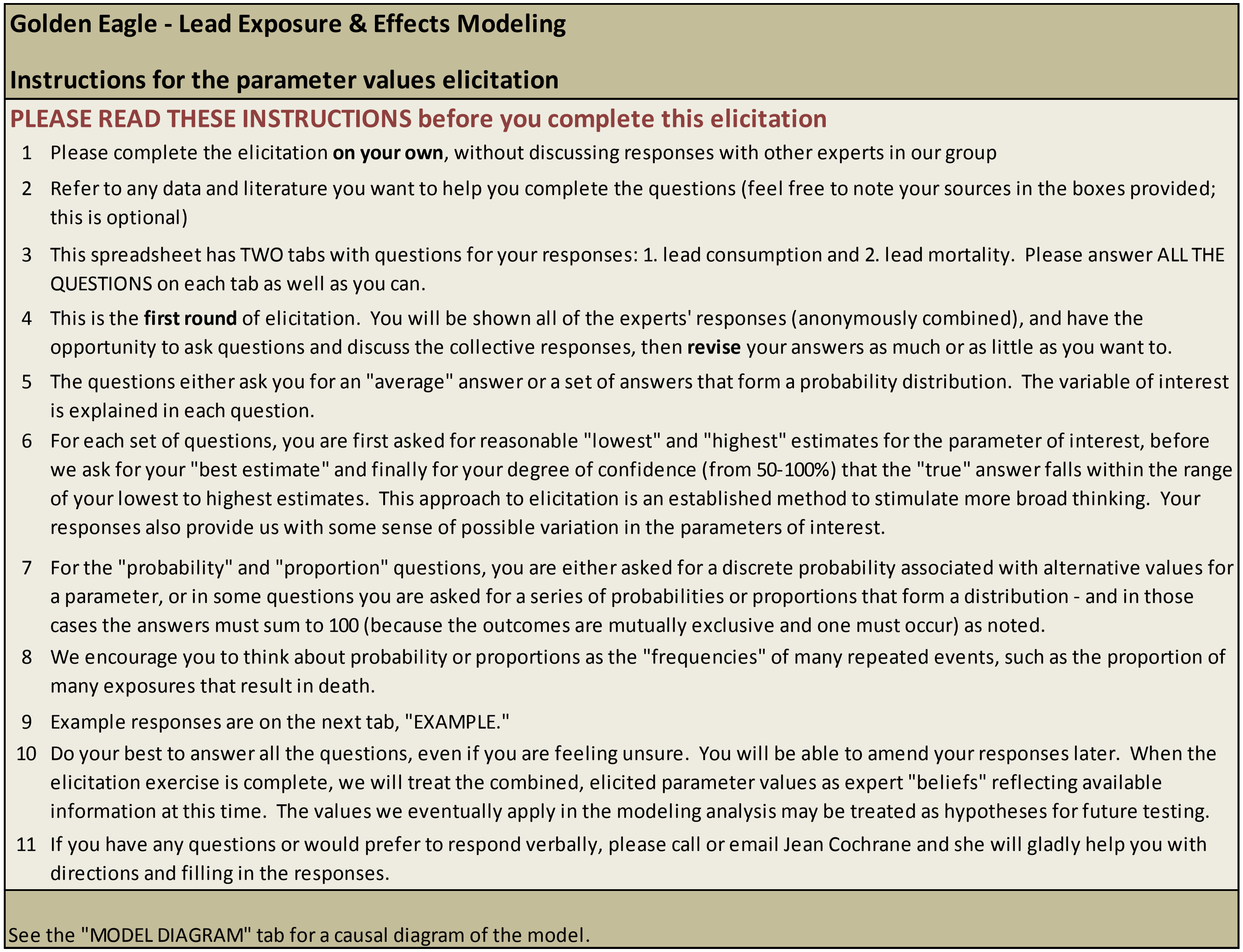
TABLE B1. Expert advisors and elicitation subjects, indicating who attended the in-person workshop at the start of the project (August, 2012), who participated in remote participation via webinars, and which experts provided quantitative estimates in formal parameter elicitation (S for scavenging rate, T for lead ingestion and mortality rates).

Name	Affiliation	Workshop	Webinar(s)	Elicitation
Bryan Bedrosian	Beringea South Consulting		X	
Pete Bloom	Bloom Consulting	X	X	S
Emily Bjerre	USFWS		X	
Mike Collopy	University of Nevada, Reno	X	X	S
Chris Franson	USGS Wildlife Health Lab		X	T
Al Harmata	University of Montana		X	
Grainger Hunt	Peregrine Fund		X	
Todd Katzner	West Virginia University	X	X	S
Terra Kelly	University of California, Davis		X	T
Mike Kochert	USGS University of Idaho	X	X	S
Brian Millsap	USFWS	X	X	
Bob Murphy	USFWS	X	X	
Leslie New	USGS Patuxent Research Center	X	X	
Pat Redig	University of Minnesota		X	T
Bruce Rideout	San Diego Zoo		X	T
Jessica Wilkinson	Environmental Law Institute	X	X	



Golden Eagle - Lead Exposure & Effects Modeling

Instructions for the parameter values elicitation

PLEASE READ THESE INSTRUCTIONS before you complete this elicitation

1 Please complete the elicitation **on your own**, without discussing responses with other experts in our group

2 Refer to any data and literature you want to help you complete the questions (feel free to note your sources in the boxes provided; this is optional)

3 This spreadsheet has TWO tabs with questions for your responses: 1. lead consumption and 2. lead mortality. Please answer ALL THE QUESTIONS on each tab as well as you can.

4 This is the **first round** of elicitation. You will be shown all of the experts' responses (anonymously combined), and have the opportunity to ask questions and discuss the collective responses, then **revise** your answers as much or as little as you want to.

5 The questions either ask you for an "average" answer or a set of answers that form a probability distribution. The variable of interest is explained in each question.

6 For each set of questions, you are first asked for reasonable "lowest" and "highest" estimates for the parameter of interest, before we ask for your "best estimate" and finally for your degree of confidence (from 50-100%) that the "true" answer falls within the range of your lowest to highest estimates. This approach to elicitation is an established method to stimulate more broad thinking. Your responses also provide us with some sense of possible variation in the parameters of interest.

7 For the "probability" and "proportion" questions, you are either asked for a discrete probability associated with alternative values for a parameter, or in some questions you are asked for a series of probabilities or proportions that form a distribution - and in those cases the answers must sum to 100 (because the outcomes are mutually exclusive and one must occur) as noted.

8 We encourage you to think about probability or proportions as the "frequencies" of many repeated events, such as the proportion of many exposures that result in death.

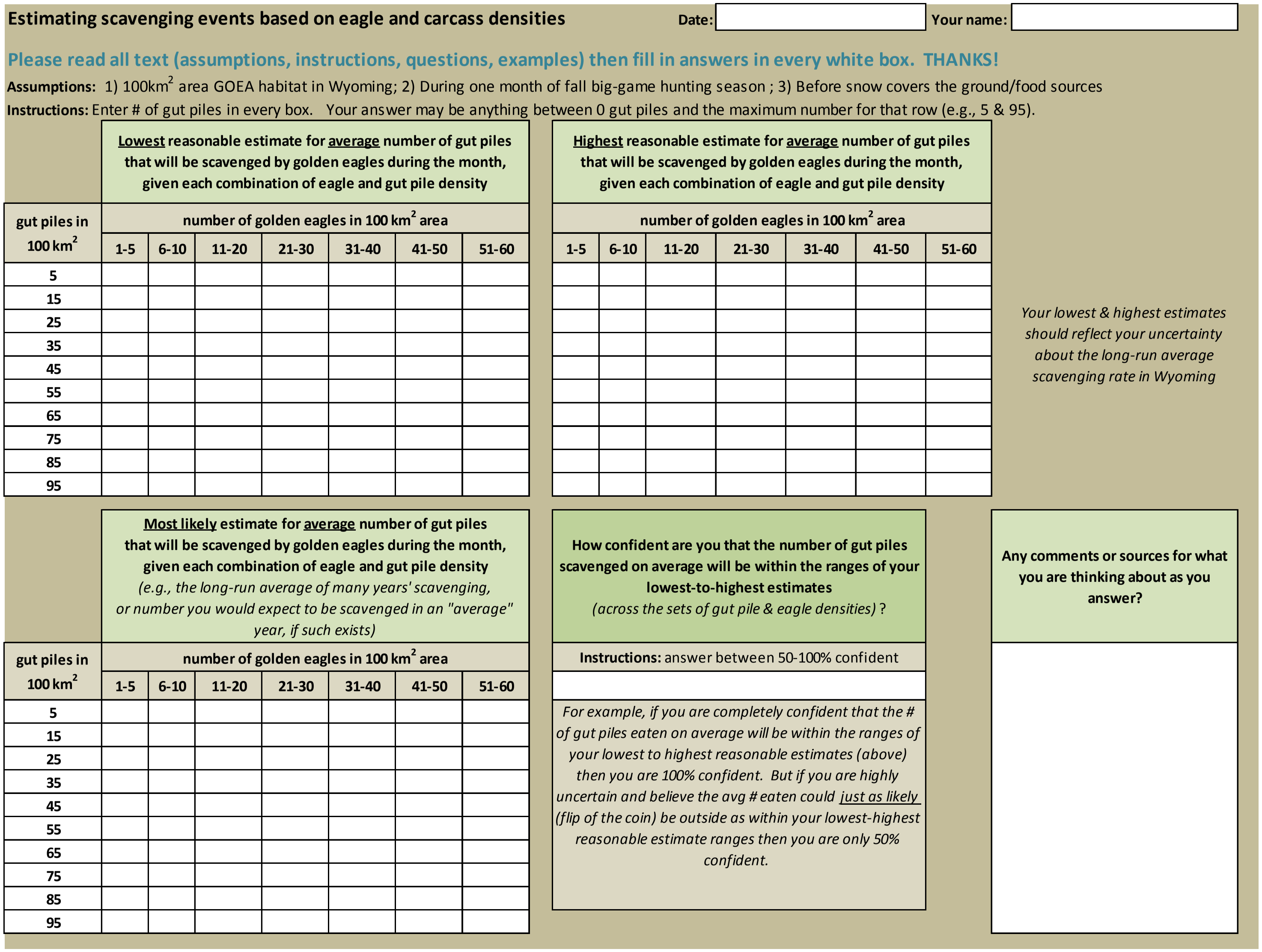
9 Example responses are on the next tab, "EXAMPLE."

10 Do your best to answer all the questions, even if you are feeling unsure. You will be able to amend your responses later. When the elicitation exercise is complete, we will treat the combined, elicited parameter values as expert "beliefs" reflecting available information at this time. The values we eventually apply in the modeling analysis may be treated as hypotheses for future testing.

11 If you have any questions or would prefer to respond verbally, please call or email Jean Cochrane and she will gladly help you with directions and filling in the responses.

See the "MODEL DIAGRAM" tab for a causal diagram of the model.

FIG. B1. Example of instructions for expert elicitation, from the first round elicitation of toxicology parameters.



Estimating scavenging events based on eagle and carcass densities **Date:** **Your name:**

Please read all text (assumptions, instructions, questions, examples) then fill in answers in every white box. THANKS!

Assumptions: 1) 100km^2 area GOEA habitat in Wyoming; 2) During one month of fall big-game hunting season ; 3) Before snow covers the ground/food sources

Instructions: Enter # of gut piles in every box. Your answer may be anything between 0 gut piles and the maximum number for that row (e.g., 5 & 95).

Lowest reasonable estimate for average number of gut piles that will be scavenged by golden eagles during the month, given each combination of eagle and gut pile density

gut piles in 100 km^2	number of golden eagles in 100 km^2 area						
	1-5	6-10	11-20	21-30	31-40	41-50	51-60
5							
15							
25							
35							
45							
55							
65							
75							
85							
95							

Highest reasonable estimate for average number of gut piles that will be scavenged by golden eagles during the month, given each combination of eagle and gut pile density

number of golden eagles in 100 km^2 area						
1-5	6-10	11-20	21-30	31-40	41-50	51-60

Your lowest & highest estimates should reflect your uncertainty about the long-run average scavenging rate in Wyoming

Most likely estimate for average number of gut piles that will be scavenged by golden eagles during the month, given each combination of eagle and gut pile density
(e.g., the long-run average of many years' scavenging, or number you would expect to be scavenged in an "average" year, if such exists)

gut piles in 100 km^2	number of golden eagles in 100 km^2 area						
	1-5	6-10	11-20	21-30	31-40	41-50	51-60
5							
15							
25							
35							
45							
55							
65							
75							
85							
95							

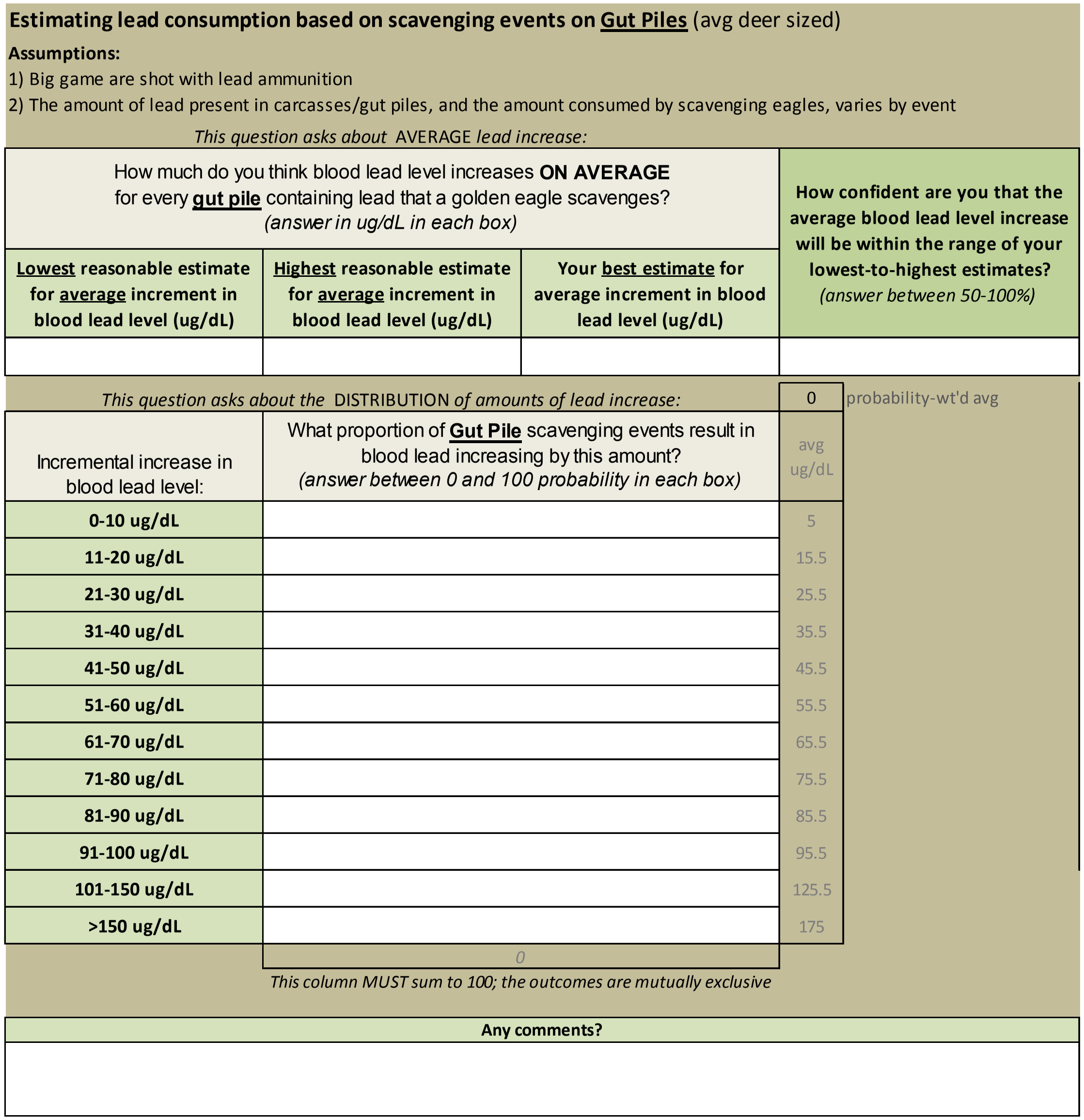
How confident are you that the number of gut piles scavenged on average will be within the ranges of your lowest-to-highest estimates
(across the sets of gut pile & eagle densities) ?

Instructions: answer between 50-100% confident

For example, if you are completely confident that the # of gut piles eaten on average will be within the ranges of your lowest to highest reasonable estimates (above) then you are 100% confident. But if you are highly uncertain and believe the avg # eaten could just as likely (flip of the coin) be outside as within your lowest-highest reasonable estimate ranges then you are only 50% confident.

Any comments or sources for what you are thinking about as you answer?

FIG. B2. Expert elicitation form for scavenging rate, from the final round elicitation of scavenging parameters.



Estimating lead consumption based on scavenging events on Gut Piles (avg deer sized)

Assumptions:
1) Big game are shot with lead ammunition
2) The amount of lead present in carcasses/gut piles, and the amount consumed by scavenging eagles, varies by event

This question asks about AVERAGE *lead increase:*

How much do you think blood lead level increases **ON AVERAGE** for every **gut pile** containing lead that a golden eagle scavenges? *(answer in ug/dL in each box)*			**How confident are you that the average blood lead level increase will be within the range of your lowest-to-highest estimates?** *(answer between 50-100%)*
Lowest reasonable estimate for average increment in blood lead level (ug/dL)	**Highest reasonable estimate for average increment in blood lead level (ug/dL)**	**Your best estimate for average increment in blood lead level (ug/dL)**	

This question asks about the DISTRIBUTION *of amounts of lead increase:*

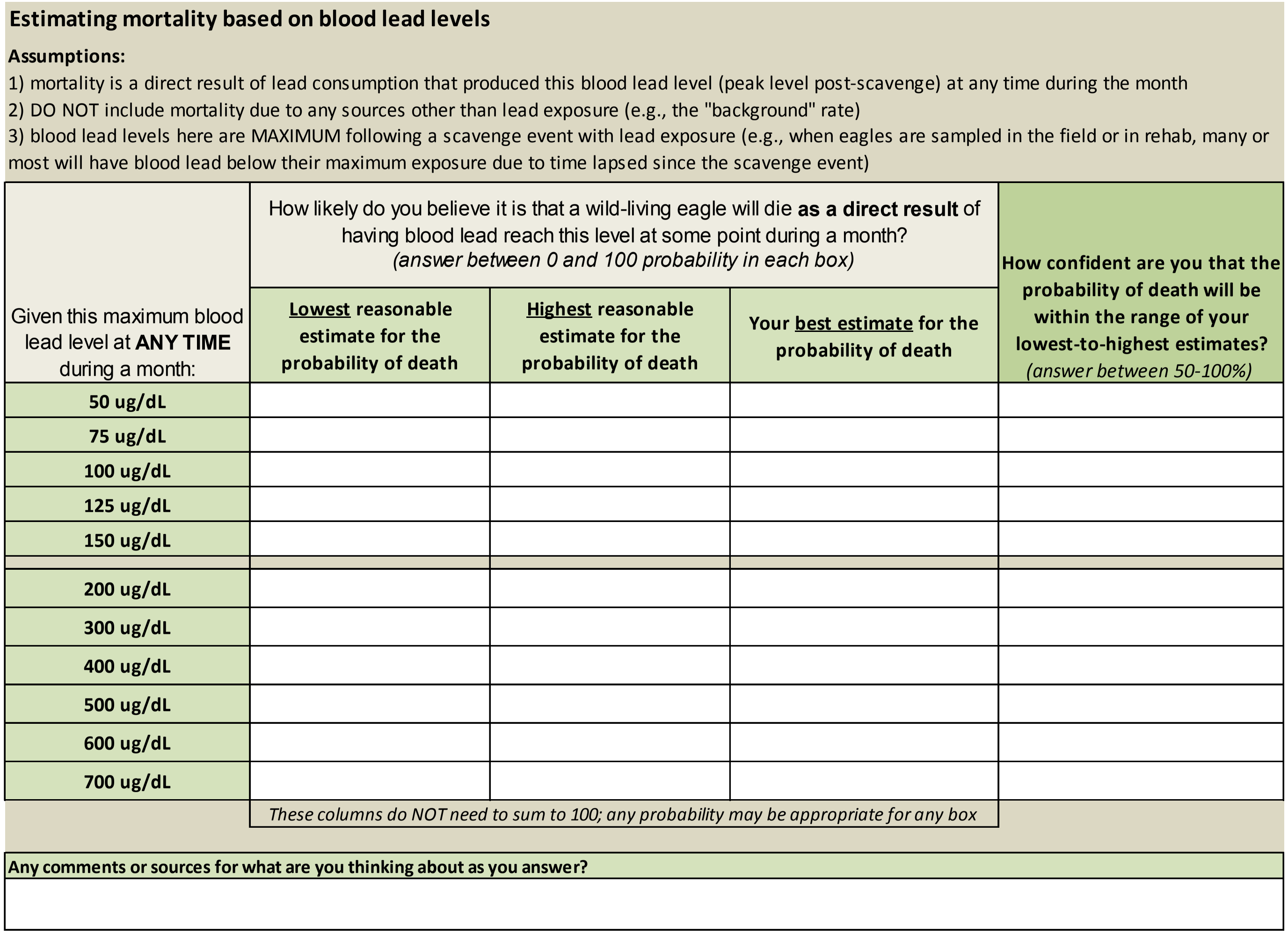
Incremental increase in blood lead level:	What proportion of **Gut Pile** scavenging events result in blood lead increasing by this amount? *(answer between 0 and 100 probability in each box)*	0 avg ug/dL
0-10 ug/dL		5
11-20 ug/dL		15.5
21-30 ug/dL		25.5
31-40 ug/dL		35.5
41-50 ug/dL		45.5
51-60 ug/dL		55.5
61-70 ug/dL		65.5
71-80 ug/dL		75.5
81-90 ug/dL		85.5
91-100 ug/dL		95.5
101-150 ug/dL		125.5
>150 ug/dL		175
	0	

probability-wt'd avg

This column MUST sum to 100; the outcomes are mutually exclusive

Any comments?

FIG. B3. Expert elicitation form for blood lead exposure rate, from the final round elicitation of toxicology parameters.



Estimating mortality based on blood lead levels

Assumptions:

1) mortality is a direct result of lead consumption that produced this blood lead level (peak level post-scavenge) at any time during the month
2) DO NOT include mortality due to any sources other than lead exposure (e.g., the "background" rate)
3) blood lead levels here are MAXIMUM following a scavenge event with lead exposure (e.g., when eagles are sampled in the field or in rehab, many or most will have blood lead below their maximum exposure due to time lapsed since the scavenge event)

Given this maximum blood lead level at **ANY TIME** during a month:	How likely do you believe it is that a wild-living eagle will die **as a direct result** of having blood lead reach this level at some point during a month? *(answer between 0 and 100 probability in each box)*			**How confident are you that the probability of death will be within the range of your lowest-to-highest estimates?** *(answer between 50-100%)*
	Lowest reasonable estimate for the probability of death	**Highest reasonable estimate for the probability of death**	**Your best estimate for the probability of death**	
50 ug/dL				
75 ug/dL				
100 ug/dL				
125 ug/dL				
150 ug/dL				
200 ug/dL				
300 ug/dL				
400 ug/dL				
500 ug/dL				
600 ug/dL				
700 ug/dL				

These columns do NOT need to sum to 100; any probability may be appropriate for any box

Any comments or sources for what are you thinking about as you answer?

FIG. B4. Expert elicitation form for mortality rate, from the final round elicitation of toxicology parameters.

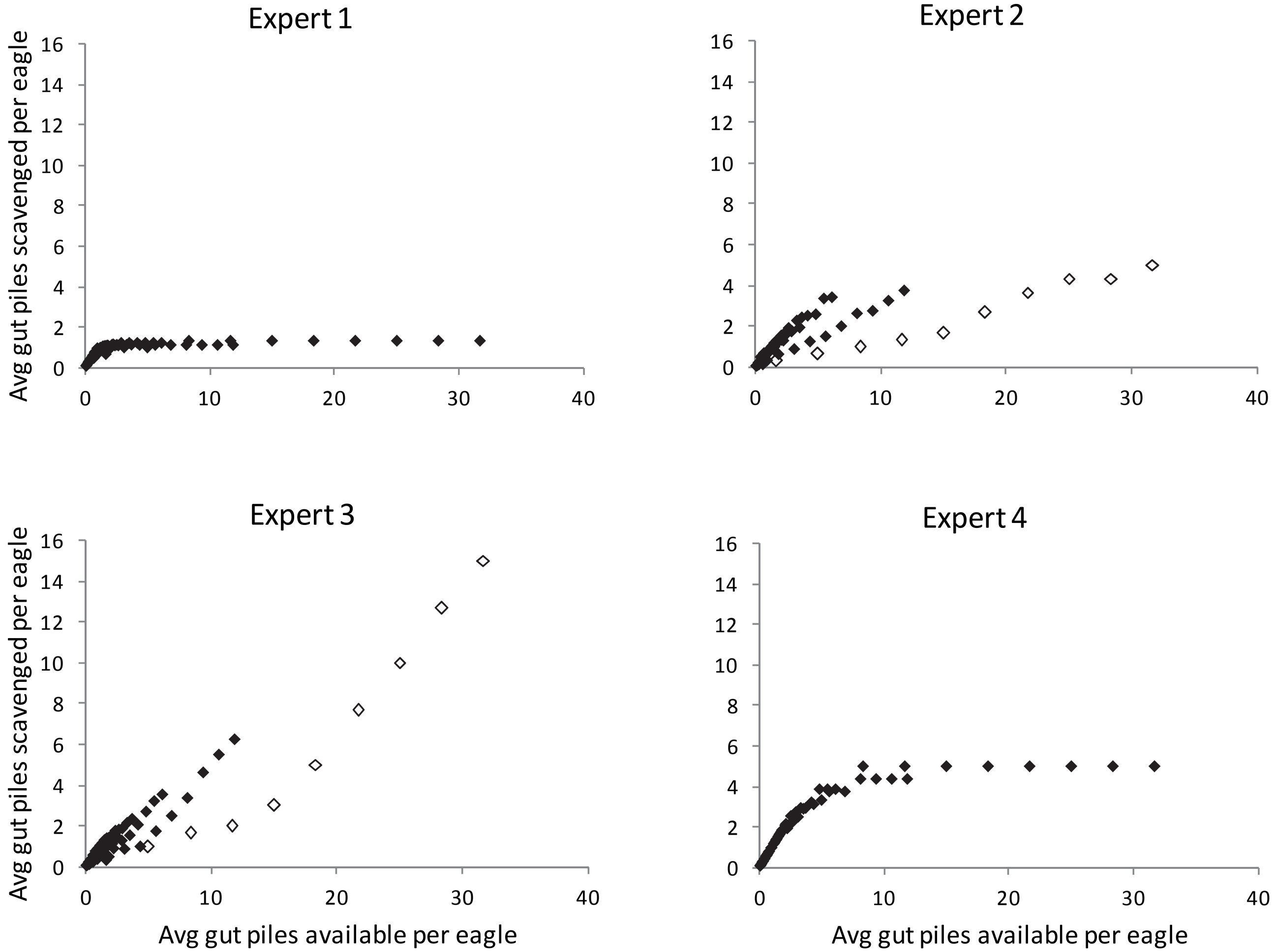


FIG. B5. Final elicitation results from four experts for the Golden Eagle scavenging rate on gut piles in a month of big game hunting season (shown as gut piles available and scavenged *per eagle*, calculated for most likely estimates for total gut piles scavenged and the average number of eagles per eagle density range2). Experts 2 and 3 anticipate that at lower eagle densities (≤10/100km^2), relatively fewer gut piles will be detected and consumed per eagle; for example, the open symbols in their graphs indicate expected gut piles scavenged per eagle when density is only 1–5 Golden Eagles/100km^2. Three experts expect that eagles will eat no more than 1(expert 1) or 5 (experts 2 and 4) gut piles in a month, while expert 3 anticipates consumption to continue increasing.

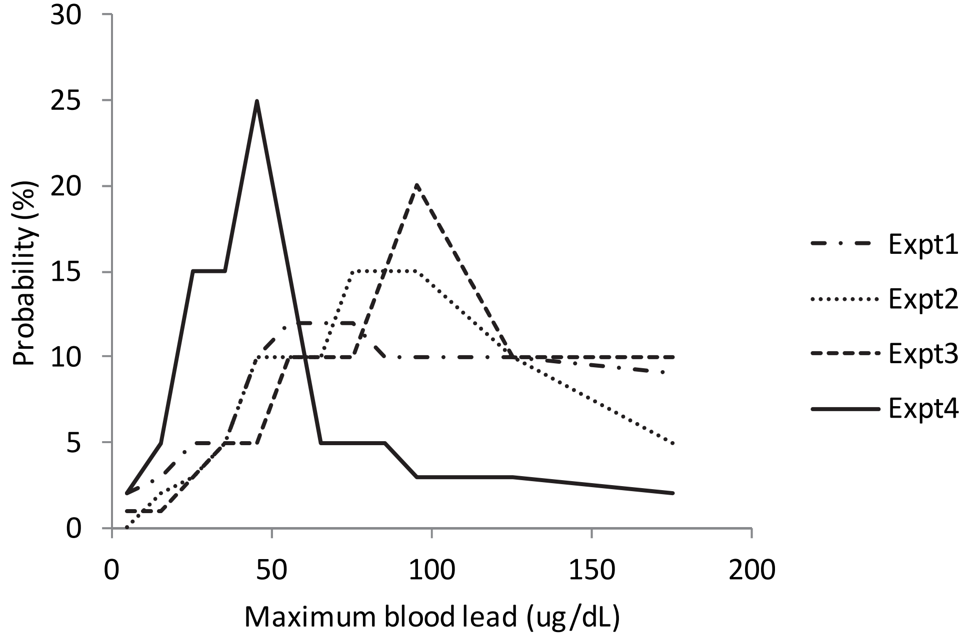


FIG. B6. Final elicitation results from four experts for the maximum blood lead level in Golden Eagles after scavenging a big game gut pile. Probabilities were elicited for ranges of blood lead level, but graphed here by the median level of each interval (for example, the probability associated with a blood lead in the 11–20*ug/dL* range is graphed at 16*ug/dL* and 175*ug/dL* for the >150*ug/dL* interval).

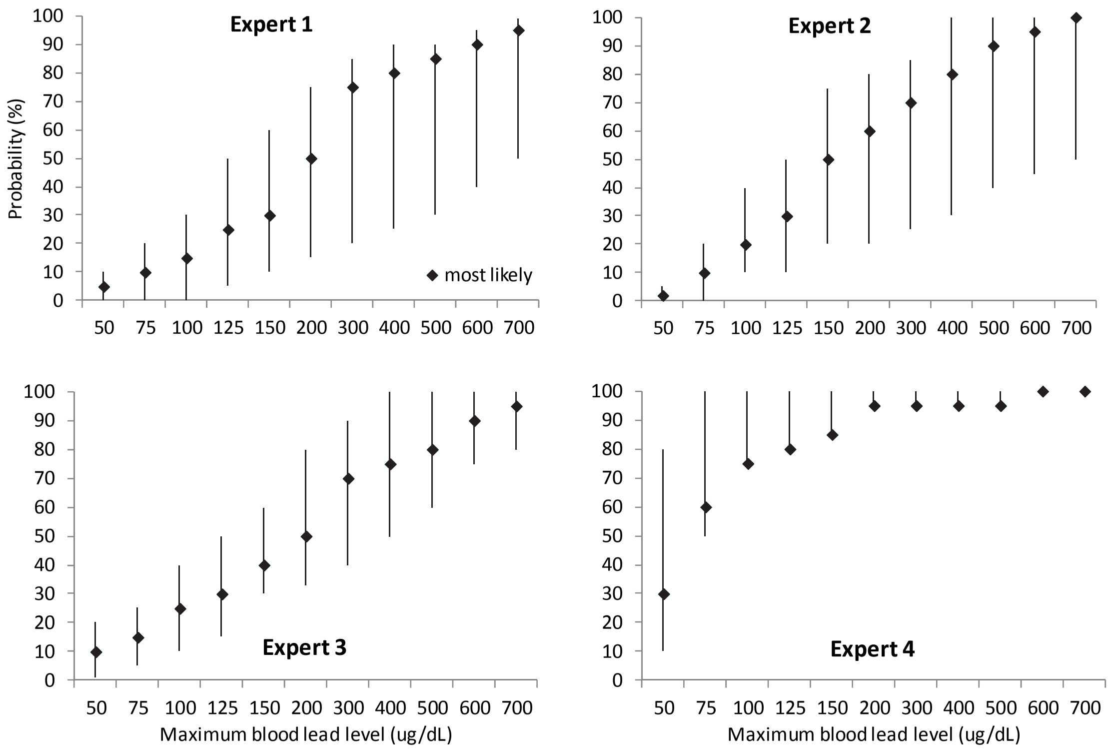


FIG. B7. Final elicitation results from four experts for the probability that a Golden Eagle will die based on maximum blood lead level following scavenge on a big game gut pile. Bars indicate the range from the lowest to highest "reasonable" estimates for the probability of death; diamonds indicate the expert's "most likely estimate" for probability of death given the maximum blood lead level (in *ug/dL*).

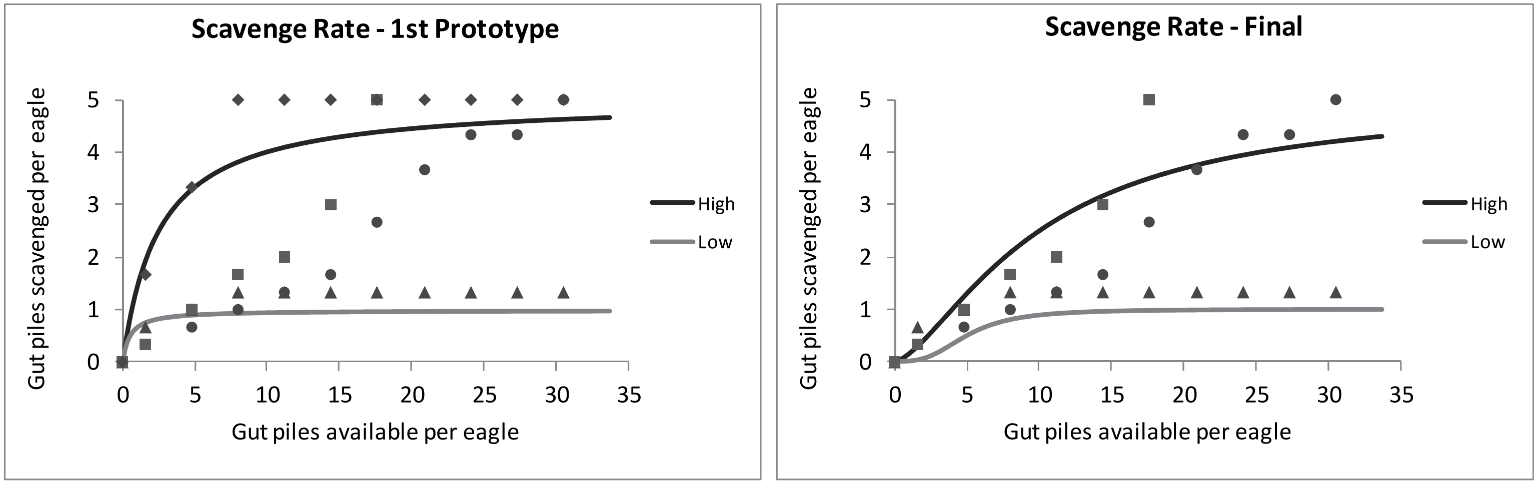


FIG. B8. Scavenging rate curves from the first prototype broadly covering the full range of variation among the elicited "most likely" values (left), and from the final model runs where we drew curves more closely representing three of the four experts (omitting the high outlier) and switching from Type II to mildly Type III saturation (right). Markers show values from experts (elicited by increments of 5 gut piles and ranges of eagle density; see Fig. B5). The low and high curves represent the lower and upper bounds (associated with expected average maximum gut piles scavenged, $C^{*} = 1$ and 5, respectively) for a uniform distribution of potential scavenging rates at any level of gut piles available per eagle (Eq. C.1 in Appendix C).

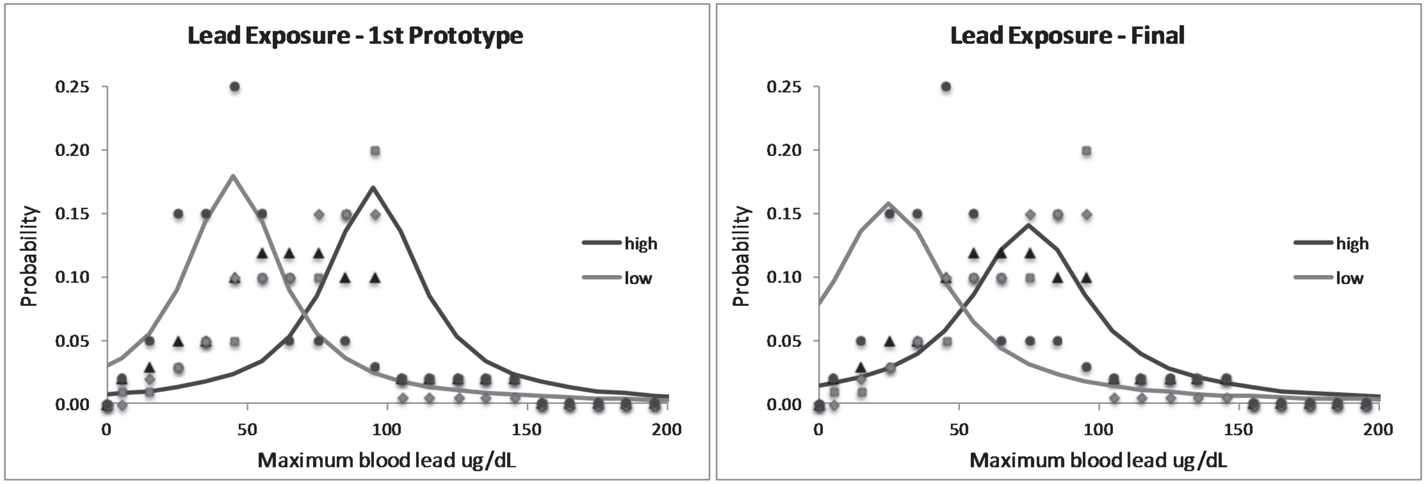


FIG. B9. Blood lead exposure rate curves from the first prototype broadly covering the full range of variation among the elicited "most likely" values (left), and from the final model runs with E_{mode} adjusted downward (in part to better account for small percentage of scavenge events where eagles may regurgitate any consumed lead fragments) (right). Markers show values from experts (elicited by increments of 10 *ug/dL* blood lead increase; see Fig. B6). The low and high curves represent the probability distribution for the lowest and highest $E_{mode} \sim U(25,75)$, respectively; for each simulation we draw a uniform random E_{mode} value from between those extremes to determine that simulation's curve (Eq. C.3 in Appendix C).

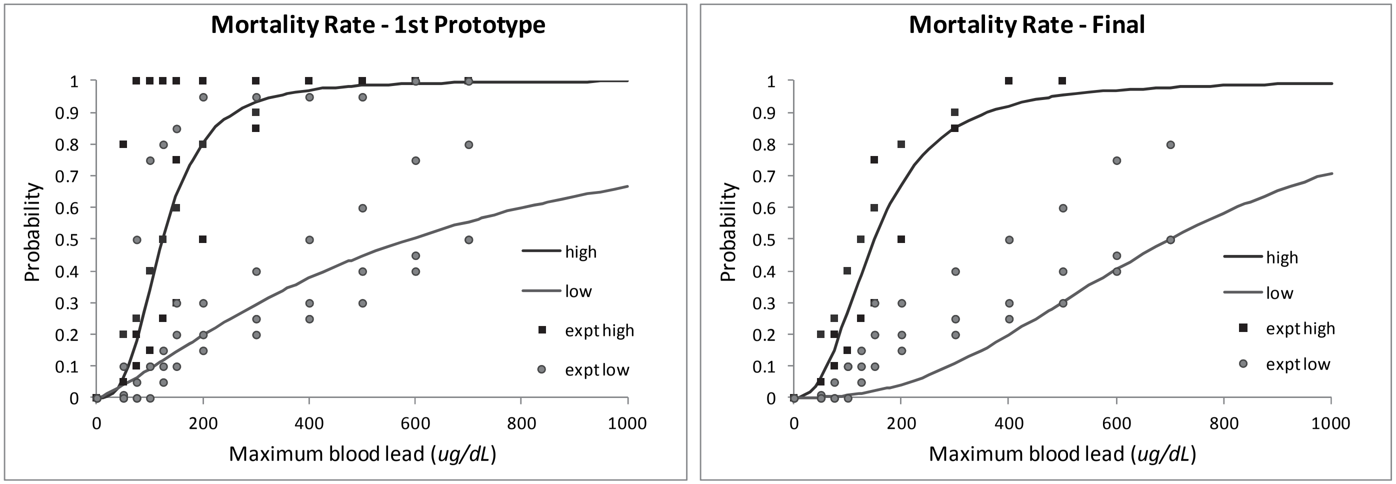


FIG. B10. Mortality rate curves from the first prototype broadly covering the full range of variation among the elicited “most likely” values (left), and from the final model runs where we drew curves more closely representing three of the four experts (omitting the high outlier) (right). Markers show values from experts (elicited by increments of 10 *ug/dL* blood lead increase; see Fig. B7). The low and high curves represent the probability distributions for the lowest and highest half-saturation values (k_m, or lead concentration for 50% mortality); for each simulation we draw a random k_m value between those extremes, to determine that simulation’s curve using a shape parameter of 2.5 (Eq. C.7 in Appendix C)