Developing a wildlife health program for the State of Montana

A Structured Decision Making Case Study from Montana Fish, Wildlife, and Parks

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Decision Problem

Montana Fish, Wildlife and Parks (MFWP) has direct experience with wildlife disease events that have seriously affected wildlife conservation and public enjoyment of wildlife resources. For the most part, MFWP only reacted to these major disease events. MFWP currently has no tools with which to determine whether taking actions to prevent major disease events will produce more desirable results than being reactive. Future wildlife disease issues in Montana are imminent, so if MFWP is going to be proactive, now is a good time. MFWP wildlife managers and biologists need risk assessment and decision support tools to help prioritize and allocate resources to identify and manage the risk of major disease events. These tools cannot provide prescriptions for local areas or populations; they need flexibility in their implementation so that decisions about wildlife management and conservation remain local and community-based.

Background

Legal, regulatory, and political context

MFWP is a decentralized organization, with much authority to make decisions affecting wildlife populations (e.g., harvest quotas, habitat management, etc.) resting with regional wildlife biologists and program managers. Typically, regional wildlife biologists and wildlife program managers work closely with stakeholders in local communities when forming recommendations about wildlife conservation actions. Regional staff also collect and use all of the necessary supporting information needed for their proposals. Central staff in Helena coordinates this process, but with rare exceptions they do not modify regional proposals or plans. Modification of regional proposals by central staff usually only occurs when statewide issues or policies are affected by local plans. Additionally, central staff is available to assist regional staff in any aspect of their decision processes. For example, the Research and Technical Services Section provides wildlife veterinary and lab expertise that is especially useful relative to wildlife health and diseases. Ultimately, all decisions about wildlife in Montana rest with the MFWP Commission. Regional proposals, assembled at the Helena level, are forwarded to the Commission for consideration. The Commission has the authority to modify actions or decisions, but usually they depend on staff expertise and decision framing when making their decisions.

Ecological context

Wildlife health is becoming an important aspect of wildlife management in many states across the U.S. Emerging wildlife diseases such as chronic wasting disease (CWD) highlight the importance of early detection of disease. Occurrences of diseases such as brucellosis and tuberculosis, which are both zoonotic and transmissible to domestic livestock, bring to light the importance not only of disease information, but also of baseline wildlife health data and its potential to facilitate proactive rather than reactive action. In reaction to the discovery of new disease outbreaks in wildlife, or even to the threat of new disease outbreaks in wildlife, large government programs are often created that are usually focused on the collection of disease monitoring data (as exemplified by Avian Influenza and White-Nose Syndrome [WNS] in bats). Wildlife disease outbreaks can also have devastating impacts on species or populations of a species. Recently, pneumonia has resulted in large die-offs within populations of bighorn sheep across the western United States, necessitating extensive culling efforts in an attempt to control spread of the disease and loss of individual populations and in some instances, meta-populations.

Decision Structure

We structured our decision to reflect the Agency structure and the nature of wildlife diseases, in that they affect populations of particular species in particular areas and management decisions are made at these local scales. We therefore describe a Montana wildlife health program that has a unifying, general problem statement and overarching, general objectives that are consistent with the conservation of any wildlife species or population in Montana. These general program objectives will be honed specifically for different wildlife species and health issues. Management actions and alternatives for particular wildlife species and disease issues are specific to local areas or regions in Montana, but can be generalized into categories of aggressive proactive actions, moderate proactive actions, and reactive actions (which typically is the status quo management alternative). To a large degree the predicted and realized consequences of management actions are also likely to be specific to local areas and regions in Montana. However, a set of models to predict the consequences of management actions on specific wildlife species and health issues can be developed to assist in making those local and regional predictions. Employing these models across Montana will facilitate a consistent approach to the way in which local decisions are made. In addition to site-specific consequence predictions, value weights for objectives, tradeoffs, and risk tolerance are likely to be specific to each regional wildlife biologist or program manager with responsibility for making decisions about a particular population of wildlife, which may also differ from the MFWP Commission when ultimate decisions are made.

Objectives

In our workshop, as a prototype we developed a set of nested objectives for a general, proactive wildlife health program in Montana (Fig. 1):

1. Maximize population health, which includes two subobjectives: maximize the probability of population persistence and minimize the probability of a major disease outbreak occurring that leads to a major die-off of a wildlife population.

2. Minimize risks posed by wildlife, which includes subobjectives to minimize risk of disease transmission to livestock and to people.

3. Minimize costs, including subobjectives to minimize operating costs, personnel costs, and costs associated with responding to crises.

4. Maximize public satisfaction, which includes subobjectives to maximize both non-consumptive and hunting opportunities.

These are prototype objectives that will need further input and development from stakeholders and FWP staff. Note that these objectives can be characterized as general objectives for wildlife management and conservation, whether we are considering wildlife health threats or other threats to wildlife conservation. In this way, we have defined a manner in which a wildlife health program can contribute to and be integrated into a more general wildlife management and conservation program. The program is focused on dealing with wildlife health threats, but the objectives remain focused on wildlife conservation. Therefore, if a wildlife health issue does not affect wildlife conservation, no action or focus of the wildlife program is warranted.

To illustrate the decision structure and how the overarching Montana wildlife health program might be applied, we used pneumonia outbreaks among bighorn sheep populations as a case study for working through our decision analysis. This decision analysis provides the groundwork to fulfill a management need of establishing a systematic health-monitoring and disease management program as mentioned in the Montana Bighorn Sheep Conservation Strategy (Montana Fish, Wildlife and Parks 2009). For application to management of pneumonia outbreaks in bighorn sheep, we narrowed the objectives to reflect the management context unique to bighorn sheep (Figure 2):

1. Maximize the probability of population persistence, which we propose to measure by determining if populations are within objectives or not, as defined by the Montana Bighorn Sheep Conservation Strategy. The persistence of populations depends on social tolerance as much as biological carrying capacity and stochastic persistence risks associated with small populations, and MFWP has already established population objectives that consider both social tolerance and biological carrying capacity.

2. Minimize costs, including operational costs, personnel costs, and crisis response costs. We will measure this objective using actual costs incurred, in dollars and/or personnel time, over a 10-year period.

3. Maximize public satisfaction, including viewing and hunting opportunities. Public viewing opportunities will be measured using the criteria of whether populations are within objective or not. Public hunting opportunity will be measured by the predicted number of licenses issued over a 10-year period.

Therefore, for application to bighorn sheep and pneumonia events, we eliminated objectives related to minimizing risks posed to humans and livestock and related to minimizing the probability of a major disease event. Bighorn sheep die-off events related to pneumonia events pose no documented threats to humans or livestock. We defined a major disease event for bighorn sheep as a die-off event in which more than 50% of the population is eliminated. We incorporated concerns related to the probability of a major disease event into our predictive model of the impact of management actions on the risk of a major disease event (see below).

Alternative actions

Alternative management actions are specific to each population of animals, and are decided upon by regional wildlife managers and biologists working with stakeholders in local communities. Further, management actions for any wildlife disease or health issue will be unique to the disease, wildlife species, location, and social context in question; no general approach will work for all situations. For managing outbreaks of pneumonia within a bighorn sheep herd, we envision possible actions managers and biologists could take falling within 3 categories:

1. React to a major disease event. This involves population declines leading to populations failing to meet defined objectives; allocating staff time and resources to cull sick bighorn sheep, collecting and processing biological samples; sample analysis fees; increased monitoring to detect recovery of collapsed populations; as well as almost invariably the cession of viewing and hunting opportunity.

2. Moderate proactive management actions. These actions will be specific to the resources available, realistic possibilities, and the situation as determined by regional wildlife managers and biologists. These may include contacting and communicating with landowners or livestock producers to affect the distance between bighorn sheep and domestic sheep or goats, removing bighorn sheep that commingle with domestics in order to affect the distance between bighorn sheep and domestic sheep or goats, and other actions.

3. Aggressive proactive management actions. These actions will be specific to the resources available, realistic possibilities, and the situation as determined by regional wildlife managers and biologists. These may include fencing domestic sheep herds to limit interactions between bighorn sheep and domestic sheep or goats, increasing ram harvest in order to affect a decline in the ram:ewe ratio (thereby preventing the spread of disease by wandering rams during rut), and other actions.

Predictive model

Historically, it has been difficult for Montana wildlife managers to anticipate wildlife disease outbreaks, making proactive management nearly impossible. We suggest that development of predictive models for the risk of wildlife disease events would help wildlife managers in their decision making processes. These models can be standardized to apply to a particular species or wildlife disease situation, so that managers of wildlife populations across the state (or at another reasonable scale) characterize and incorporate risk into their decisions in the same manner, while continuing to apply their local knowledge of wildlife populations and management options.

To illustrate this, we developed a risk assessment model to predict the probability of a major disease outbreak for a herd of bighorn sheep over 1-year and 10-year time horizons. We defined a major disease event as one with ≥ 50% mortality due to disease within 10 years. The model was simple, structured as Pr(major disease event) = Pr(exposure) x Pr(susceptibility) x Pr(spread). We implemented the model as a spreadsheet, for which managers of individual bighorn sheep herds can use their monitoring data or expert knowledge to parameterize model inputs and obtain predicted probabilities of a major disease outbreak on 1-year and 10-year time horizons.

For our case study using bighorn sheep, we determined Pr(exposure) was best predicted by contact with domestic sheep and goats (primary sources of infections that lead to pneumonia outbreaks), proximity to bighorn sheep herds infected with pneumonia, and recent or historical presence of pneumonia within the bighorn sheep population. The range of potential values assigned to each reflected a subjective, relative weighting of importance as decided upon by the experience and expertise of our team. We defined Pr(exposure) as the sum of the assigned values for each, divided by the maximum possible value for the sum (Figure 3).

We determined Pr(susceptibility) could be reflected among several possible indicators, including assessments of clinical condition, habitat condition, and low recruitment of lambs (lamb mortality is high during and following pneumonia outbreaks). We estimated Pr(susceptibility) as the average value (range 0 to 3) assigned to each of 6 potential indicators, divided by 3, the maximum possible value for the average. Indicators for which no information was available were assigned a missing value and did not contribute to the average (Figure 3).

We determined Pr(spread) could be predicted by the density and distribution of bighorn herds, and the observed ratio of rams to ewes (rams range much more widely than ewes and are thought to be important vectors for spread of disease among herds). We defined Pr(exposure) as the sum of the assigned values for each, divided by 9, the maximum possible value for the sum (Figure 3).

We defined the Pr(major disease event) within the next year as the product of Pr(exposure), Pr(susceptibility), and Pr(spread). This method implicitly assumes that the relationship between the risk score and the probability of a pneumonia outbreak is linear, such that an increase in the score always leads to an increase in the probability of an outbreak. We then defined Pr(major disease event) over the next 10 years as 1 - (1 - Pr(major disease event in next year))^{10}, using the basic laws of probability.

This spreadsheet-based model was constructed so that regional wildlife biologists and managers could also predict the impacts of their management actions on the risk of a major disease event. To do this, managers can decide which component of risk their management actions are designed to mitigate; for example, fencing domestic sheep herds is designed to reduce the exposure of bighorn sheep to domestic sheep. Managers can then predict how their management actions will affect the scores for that particular component(s) of risk, input those estimates into a new model run, and thereby predict how the risk of a pneumonia event will be affected by the proposed action. Thus, the model becomes a uniform tool for managers to assess and compare alternative, local management actions.

To illustrate the usefulness of this model in informing management decisions, we parameterized the model for the Missouri Breaks bighorn sheep herd and the Petty Creek bighorn sheep herd. We chose these herds because the herd managers were present on our team, and because they represented variable situations in different parts of Montana. We parameterized the model for 3 management scenarios (no proactive management, moderate proactive management, aggressive proactive management) for each herd by eliciting values from herd managers familiar with local herd conditions as well as the knowledge of statewide technical staff.

Decision Analysis

We constructed a decision tree to estimate the consequences of the 3 management alternatives: 1) reactive management, 2) moderate proactive management, and 3) aggressive proactive management, using measurable attributes for each fundamental objective (Figure 4). Probabilities for estimating consequences under each management alternative were taken from Pr(major disease event) as predicted by our disease risk model (Figure 3). We multiplied attributes for each objective by Pr(major disease event) to estimate expected outcome of each management action (see example for Petty Creek herd; Figure 5). We normalized expected outcomes and weighted them according to the value-weighted management priorities of the particular bighorn sheep herd managers, and then we summed resulting values within management alternatives to determine relative support for each alternative (Figure 6).

To ability of this decision analysis system to assist managers in making decisions is exemplified by our analyses for the Petty Creek and Missouri Breaks herds. The 2 herds experience very different environments affecting the likelihood of disease outbreaks. The Petty Creek herd is regularly exposed to domestic sheep and goats on developed private lands. By contrast, the Missouri Breaks herd is not currently exposed to infected bighorn sheep herds, and active management to prevent association with domestic sheep in the region is ongoing. To be credible as a tool for assisting decision-making, our risk analysis model would need to distinguish the risk of a major disease event for both herds, as well as point to management actions that reflect these different levels of risk.

The risk analysis model predicted the probability of a major disease event within the next 10 years for the Petty Creek herd to be 0.56, whereas it predicted a probability of 0.18 for the Missouri Breaks herd, consistent with the expert opinion concerning these probabilities in our team. The decision analysis for the Petty Creek herd provided strong support for aggressive proactive management, modest support for moderate proactive management, and little support for reactive management (Figure 7). By contrast, the analysis for the Missouri Breaks herd showed strong support for either aggressive or moderate proactive management, with little support for no new management action (Figure 7).

Uncertainty

Both the risk analysis and decision models include assumptions and uncertainty; reducing this uncertainty would benefit this decision-making process. First and foremost, we developed models for predicting and managing disease outbreak in bighorn sheep as a case study example of how a Montana wildlife health program might be structured. Obviously a complete wildlife health program for the State would need to be more general, encompassing diseases like brucellosis, CWD, etc., and the other wildlife species that are affected by health issues. While the general framework described here should apply to all cases, developing objectives, management alternatives, and appropriate models for each situation will require focused work to construct individual, well-designed adaptive management programs. These programs will necessarily be specific to species and health issues under the general framework we provide, and will allow predictions to be improved over time so that the models become more reliable and useful as they are put to use informing actual decisions with follow-up monitoring.

For the bighorn sheep risk model, uncertainty within the risk analysis model needs to be addressed. Predicting disease outbreaks is challenging, particularly when the tools (e.g., collection and analysis of blood or other tissues) for detecting contributing factors are limited. Work is needed to:

1. Work with other experts in Montana to ensure that all aspects of the probability of pneumonia outbreaks are captured in the modeling framework, and that factors used to predict probabilities of pneumonia outbreaks are measured and weighted relative to each other in an epidemiologically-credible manner. Disagreements about factors that should be included or the relative weights of those factors in predicting the probability of an outbreak will need to be characterized as competing risk models in an Adaptive Management framework.
2. Use risk model(s) to predict disease outbreaks using the available historical data, in order to validate and calibrate the model(s) to real observations before the model(s) receive widespread use to predict new observations.
3. Conduct sensitivity analyses of the various components of the risk model as it is applied to the management of real bighorn sheep populations. The risk model contains several major assumptions, for example it assumes a linear relationship between risk scores and the probabilities of exposure, susceptibility, and spread (Figure 8). The sensitivity analysis needs to reveal the extent to which these critical assumptions affect overall predictions of the probability of disease outbreaks. If changing these assumptions affects the predicted probabilities to the extent that desired management actions would differ using different assumptions, then research is required to test the assumptions in order to make management decisions effective or alternative. Alternatively, competing models with variable assumptions could be developed in the Adaptive Management framework. When compared against monitoring data over time, the most accurate assumptions and models will become evident.

4. Design a complementary monitoring program that directly inform the factors included in the risk analysis model, allowing adaptive improvement of the model(s) through learning as they are used to inform decisions.

Discussion

Value of decision structuring

Approaching the development of a wildlife health program for Montana using Structured Decision Making concepts led to substantial progress on this program that would not have been possible otherwise. The major value of this approach came from the focused thinking and debate on the overall mission/problem statement, the objectives of the program (and how they mesh with wildlife management and conservation in general), and the discussion of the actual management alternatives. This focused thinking led to clarity on how the decision needed to be framed, and how a program like this could be structured to mesh with an agency structure that promotes local, community-based wildlife conservation rather than central, authority-based wildlife conservation. This clarity would not have been possible without carefully delineating the various elements of the actual decision.

Conversely, the value of the more technical aspects of Structured Decision Making, for example models used to predict the consequences of alternative management actions relative to meeting objectives, has been explored but not yet fully realized. To use the model we developed for the risk of major disease events in bighorn sheep herds to inform decisions about bighorn sheep management, more focused technical work is required. This technical work is possible now that the decision and program have been framed with clarity, and there is now a strong likelihood that such predictive model(s) will be useful. Predictive model(s) will be valuable to the extent they are accurate, so that decisions about bighorn sheep (or other wildlife) management are better for having used the models than they would have been otherwise.

Further development required

The concepts we developed for the wildlife health program in Montana need to be shared with wildlife conservation leadership in Montana, first and foremost. This should be done in a forum where discussion and debate is possible. This will permit the concepts we developed to be edited and changed as needed, so that the stakeholders in the program develop ownership of the program. Concurrent with and following this, the concepts need to be shared with other project leaders so that the concepts can be used in the relevant arenas. Examples of this include bighorn sheep management, the development of a Montana plan for WNS in bats, and a revision to the plan for CWD in Montana, which is forthcoming.

Second, specific to our prototype of bighorn sheep disease events, the measurable attributes relative to population objectives should be revisited. Currently, these attributes are constructed as thresholds, where a value of 1 indicates that the population is within objective bounds, and a value of 0 indicates otherwise. Populations that are not within objective bounds receive no credit, which may hinder real-world tradeoffs that wildlife managers need to make. Alternatively, the attribute may be constructed such that all population sizes within objective bounds receive the highest possible value, and population sizes outside of the objective range are scored lower the further from the objective bounds they are (*sensu* Keeney 2007). Constructing the attribute in this manner will ensure that populations within the objective bounds receive the high score they should, but populations close to these bounds will still receive a relatively high score for being closer rather than farther from the population objectives. This should allow managers the flexibility needed to make tradeoffs in management decisions when necessary.

Following this, the predictive risk model for bighorn sheep disease events needs to be further developed and refined, as described above. The general wildlife health program also needs to be expanded to include other species and wildlife health issues, as described above.

Prototyping process

The rapid-prototyping process was extremely valuable because of the efficiency with time that it afforded us. We now have an example program that we can refine, so the week spent on this issue using the prototyping process resulted in a tangible outcome. The process did lead to a conceptual roadblock as we attempted to work through the case study to develop an example. The roadblock happened because there was confusion as to why we needed to develop the details of the strategy for bighorn sheep, rather than simply the more general strategy. While roadblocks of some sort are likely inevitable in a process like this, next time this particular roadblock might be avoided if we can clearly articulate the intent and benefits of employing a case study example toward developing the broader framework.

One clear necessity that arose in our workshop was the involvement of the decision makers in the prototyping process. In developing our case study of bighorn sheep, we would have been lost without the input from actual herd managers. It will be imperative to have continued involvement from decision makers as the program is further defined and expanded to include other species, areas, and issues. Without this involvement, time will be unnecessarily wasted.

Recommendations

The Montana wildlife health program should be structured like the Agency is structured, and should be fully integrated into the broader wildlife conservation program via a focus on unifying wildlife conservation objectives. The overall mission and overarching objectives of the wildlife health program can be defined at a statewide level to be focused on managing wildlife health issues to ensure the conservation of wildlife species, as we have done. The overarching objectives need to be honed to deal with particular species or health issues, as we have exemplified in our case study concerning bighorn sheep die-offs, but the focus on wildlife conservation should remain in these refined objectives. The management alternatives need to be defined by regional wildlife managers and biologists, because this is the scale at which wildlife conservation and management decisions are made in Montana for the most part. Consistency in the approach to make decisions could be achieved with the use of the same predictive model(s) and monitoring methods, with local adaptation as necessary and logical.

The next, most important step in the development of the Montana wildlife health program is to share the concepts and ideas we developed with the wildlife conservation leadership in Montana. This will lead to refinement and editing of the program as we have defined it, allowing stakeholders to develop ownership of the program and to define and prioritize the required next steps in the development of the program.

Literature Cited

Keeney R. L. 2007. Developing objectives and attributes. Pp 104-128 *in* Edwards W., R. F. J. Miles, and D. Von Winterfeldt, editors. Advances in decision analysis: from foundations to applications. Cambridge, UK: Cambridge University Press.

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Figures

Figure 1. Fundamental objectives for a proactive wildlife health management program in Montana, with measurable attributes.

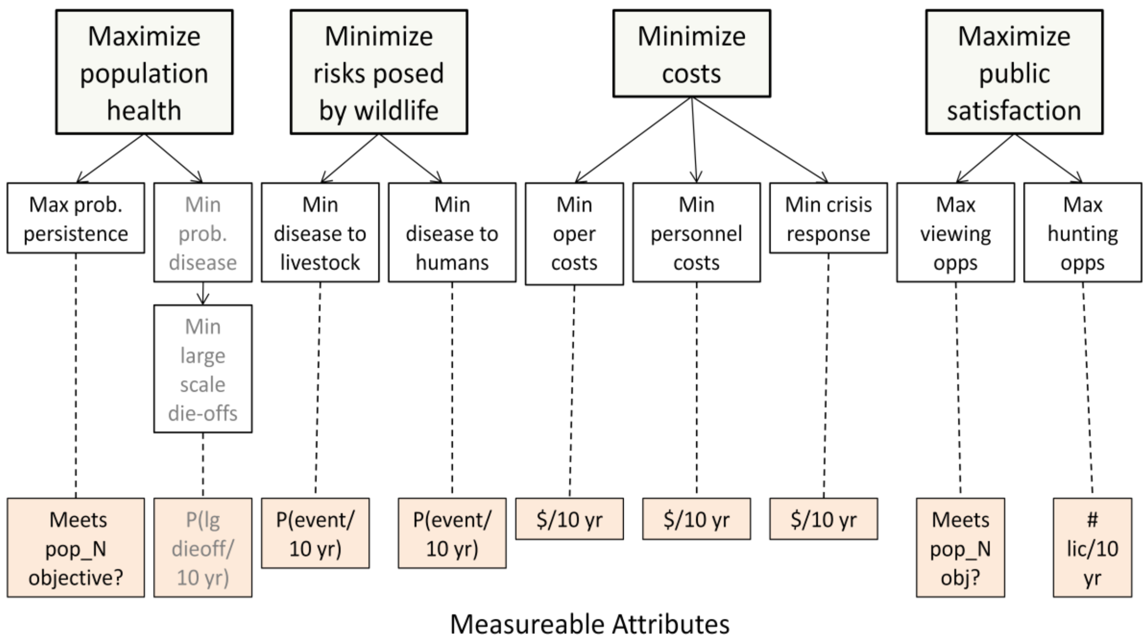

Figure 2. Objectives for a proactive wildlife health management program applied to bighorn sheep in Montana, with measurable attributes.

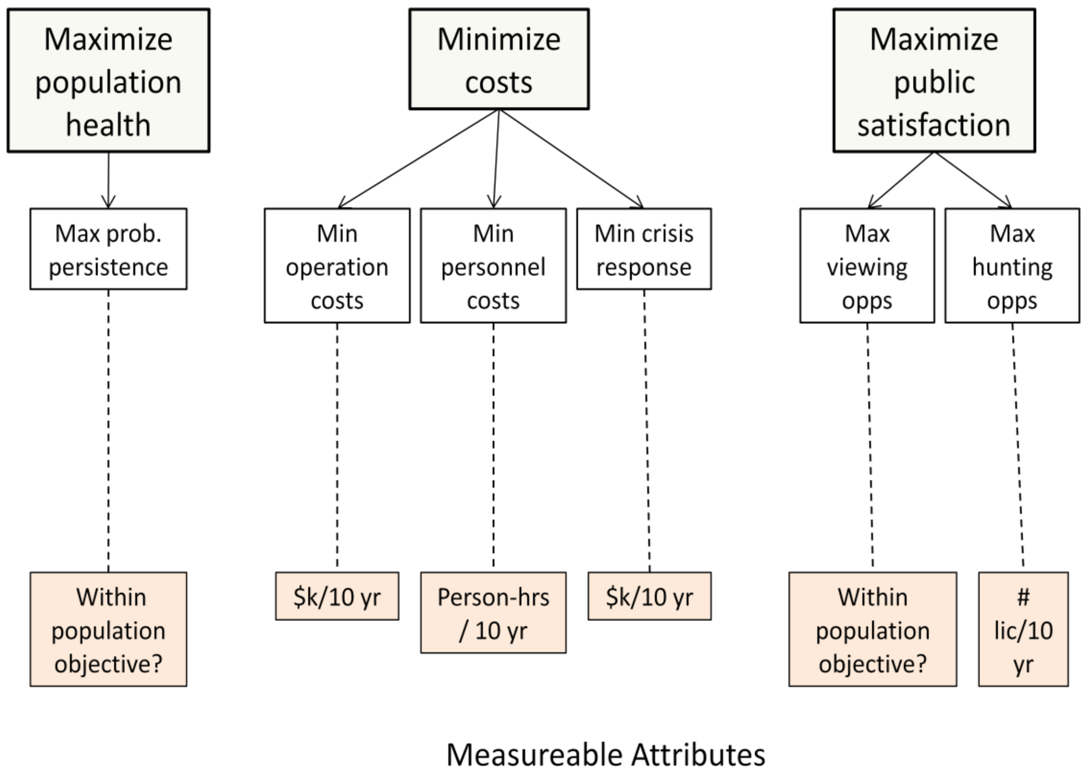

Figure 3. Model for estimating probability of a major disease event (≥50% mortality within a 10-year period) for a bighorn sheep population. The model is parameterized for no proactive management of a herd of bighorn sheep living in Petty Creek Montana.

	1 yr	10 yr
P OF MAJOR DISEASE EVENT	0.08	0.56

	sum	prob
Exposure	6	0.35

Domestic Sheep and Goats: 6

- Contact highly unlikely (0)
- Within pot'l range of forays (2)
- Within<= 7 miles (4)
- Within BHS range (6)

Proximity to infected BHS: 0

- Contact highly unlikely (0)
- Within pot'l range of forays (2)
- Within adjacent herd (4)
- Within BHS range (8)

Current presence of pathogens: 0

- Absent/unknown (0)
- Past present (1.5)
- Known present (3)

	sum	prob
Susceptibility	1	0.333

Body condition: 0

- Good (0)
- Moderate (1.5)
- Poor (3)

Parasite load: 1.5

- Low (0)
- Medium (1.5)
- High (3)

Blood parameters: .

- Low (0)
- Medium (1.5)
- High (3)

Range measures: 1.5

- Good (0)
- Moderate (1.5)
- Poor (3)

Mineral levels: .

- Good (0)
- Moderate (1.5)
- Poor (3)

Lamb:ewe ratio: 1

- Poor (3)
- Low (2)
- Medium (1)
- High (0)

	sum	prob
Risk of spread	6	0.67

Herd density: 0

- Within objectives (0)
- Slightly over objectives (1.5)
- Well over objectives 3)

Herd distribution: 3

- Normal-sized bands (0)
- Large bands, small areas (natural; 1.5)
- Large bands, small areas (artificial; 3)

Ram:ewe ratio: 3

- Low (0)
- Medium (1.5)
- High (3)

Figure 4. Decision tree for managing disease outbreaks among bighorn sheep in Montana. Probabilities (p) are derived from estimation of Pr(major disease event), Figure 3. Consequences (C) are labelled: h = heavy management, m = moderate management, n = no management, d = disease outbreak, n = no disease outbreak.

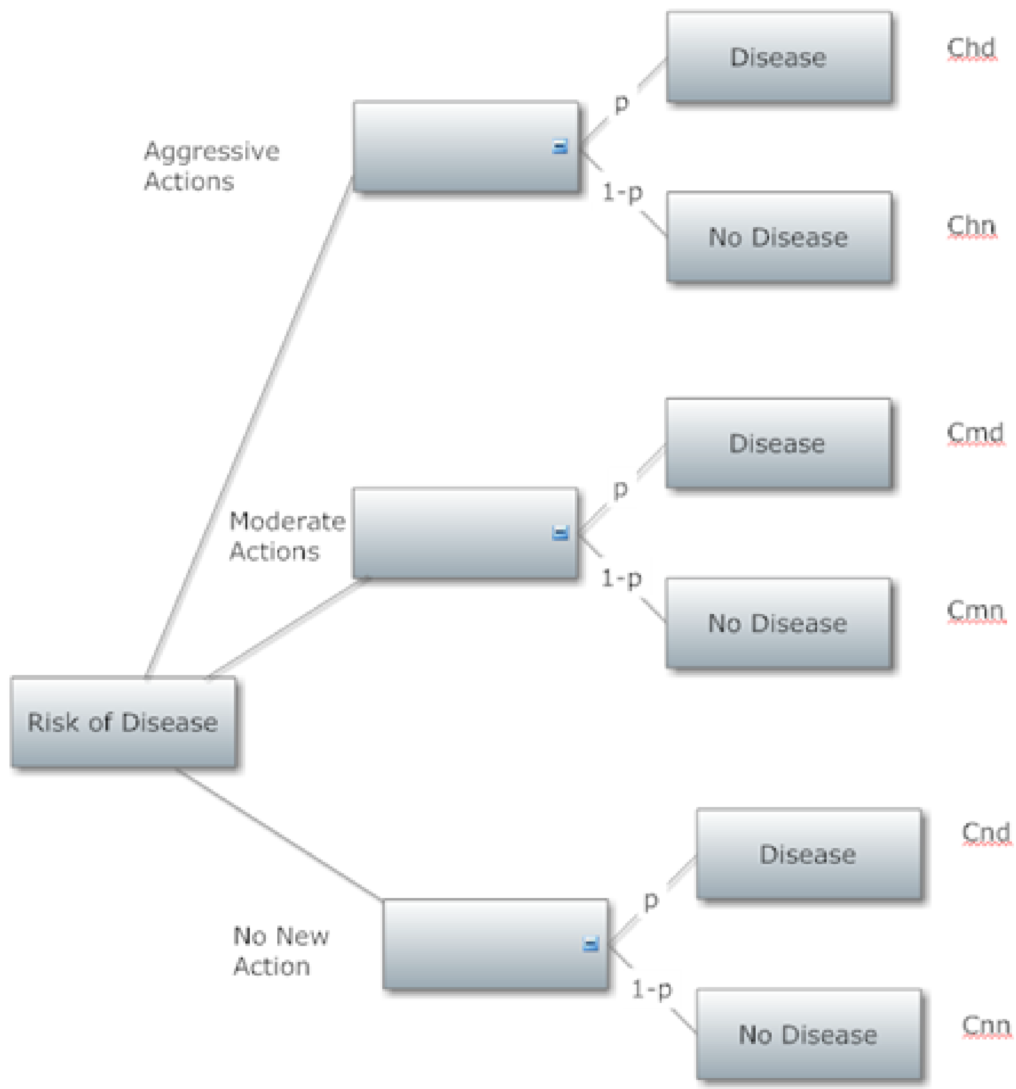

Figure 5. Estimated consequences for 3 alternative strategies for managing disease outbreak in bighorn sheep proactively, illustrated for a population of bighorn sheep living in Petty Creek, Montana. The top row consists of fundamental objectives. Probabilities of disease or no disease are estimated from our Pr(major disease event), Figure 3.

Prob. Disease		Probability of Popl Target	Operating Costs	Personnel Costs	Crisis Response	Viewing Opportunity	Hunting Opportunity
0.1	disease:	0	105	220	80	0	100
0.9	no disease:	1	105	220	0	1	200
Expected w/ Aggressive:		**0.9**	**105**	**220**	**8**	**0.9**	**190**
0.2	disease:	0	100	170	80	0	75
0.8	no disease:	1	100	170	0	1	150
Expected w/ Moderate:		**0.8**	**100**	**170**	**16**	**0.8**	**135**
0.6	disease:	0	0	0	80	0	75
0.4	no disease:	1	0	0	0	1	150
Expected w/ Reactive Management:		**0.4**	**0**	**0**	**48**	**0.4**	**105**

Figure 6. Consequences table for evaluating 3 management alternative to proactively managing disease outbreak in bighorn sheep (no proactive management, moderate proactive management, and aggressive proactive management), illustrated for a population of bighorn sheep living in Petty Creek, Montana. The top row contains fundamental objectives, the second row contains whether objectives were to be minimized or maximized, and the third row contains measurable attributes for each objective. The fourth row contains relative weights assigned to each objective by the manager of the Petty Creek herd, which sum to 1. The final 3 rows contain expected outcomes of pursuing the 3 management strategies, including the sum of normalized, weighted scores, indicating relative support of the decision-making process for each management alternative.

	Probability of persistence	**Operating Costs**	**Personnel Costs**	**Crisis Response**	**Viewing Opportunity**	**Hunting Opportunity**	
	Max	Min	Min	Min	Max	Max	
	Meet Pop Obj?	$ cost/ 10 yr	person-days/ 10 yr	$ cost/ 10 yr	Meet Pop Obj?	# lic/ 10 yr	
Weight:	**0.21**	**0.15**	**0.14**	**0.19**	**0.15**	**0.18**	
Alternative							**Sum of normalized & weighted scores**
aggressive	**0.9**	**105**	**220**	**8**	**0.9**	**190**	**0.72**
moderate	0.8	100	170	16	0.8	135	**0.53**
no new	**0.4**	**0**	**0**	**48**	**0.4**	**105**	**0.28**

Figure 7. Results of decision analyses for 2 herds of bighorn sheep in Montana, one inhabiting Petty Creek in western Montana, the other inhabiting the Missouri Breaks in central Montana. The 2 herds experience 2 different environments affecting likelihood of major disease outbreak. The Petty Creek herd is well-connected to other infected bighorn sheep herds in the region and is regularly exposed to domestic sheep and goats. By contrast the Breaks herd is relatively isolated from infected bighorn sheep and has little exposure to domestics due to ongoing proactive management. Graphs illustrate relative support for the 3 management alternatives between the 2 herds.

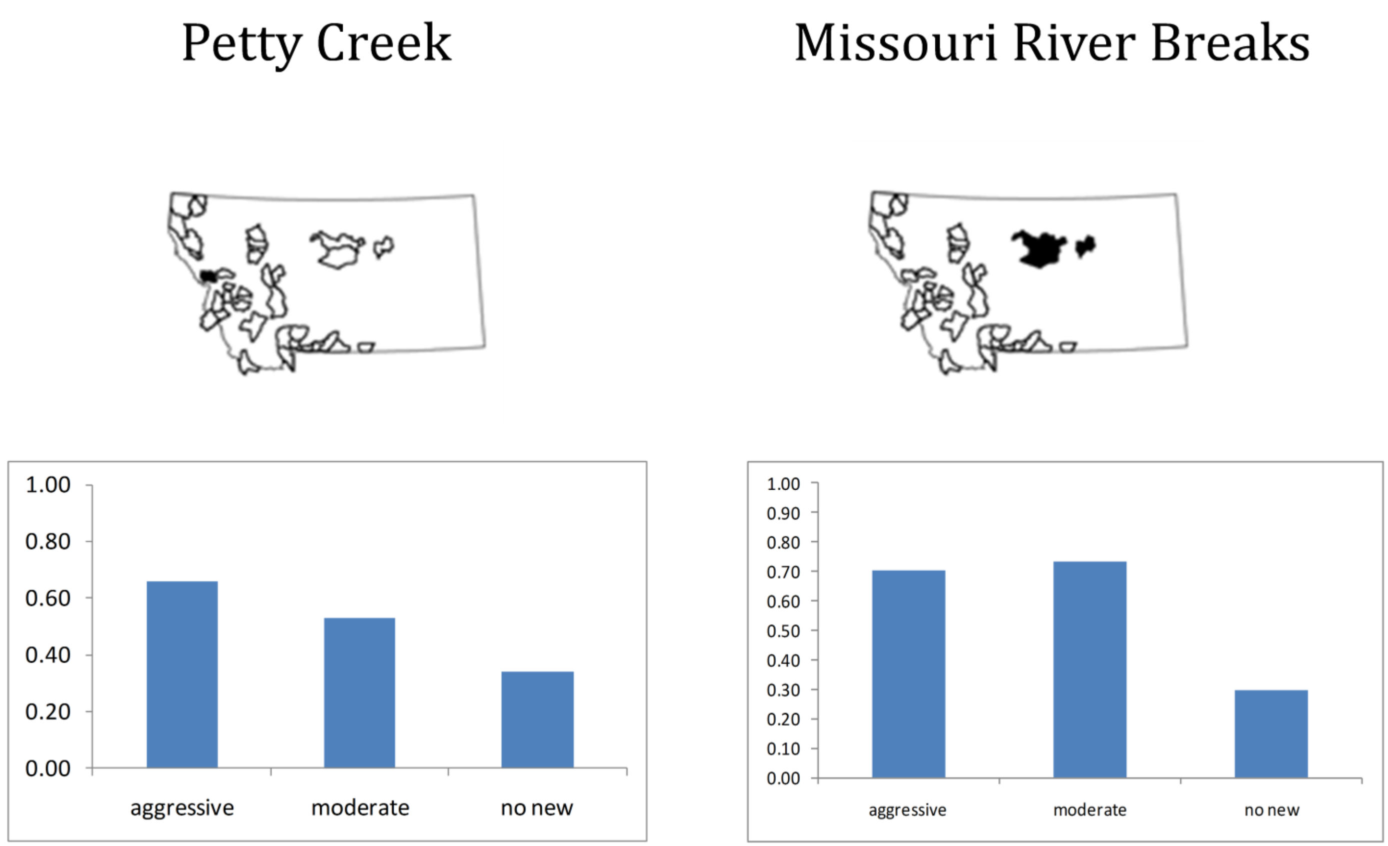

Figure 8. Modeled contributions of Pr(exposure), Pr(susceptibility) and Pr (spread) to Pr(major disease event), solid lines, and possible other forms of the relationships that need to be explored.