From:	Reid, Rebekah N
To:	tdonovan@uvm.edu
Subject:	SMART Analysis and SSAs
Date:	Wednesday, June 13, 2018 10:30:09 AM
Importance:	High

Hi Terri,

I was in the Principles of Modeling Class last semester. We recently presented a Species Status Assessment that incorporated a SMART analysis. A question came up about the validity of use for our application. If you have time, I was wondering if I could explain how we used the analysis and you provide your opinion about whether or not it is technically sound and used correctly in our application. I'll be happy to share our spreadsheet, too.

Thank you.

Rebekah Reid

US Fish and Wildlife Service
Asheville Ecological Services Field Office
160 Zillicoa St.
Asheville, NC 28801
phone: 828-258-3939 x238
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From: tdonovan@uvm.edu
To: Reid, Rebekah N
Subject: [EXTERNAL] RE: SMART Analysis and SSAs
Date: Wednesday, June 13, 2018 10:40:53 AM
Attachments: Mitchell et al 2013 BHS WSB.pdf
Robinson et al 2017 turkey.pdf
Importance: High

Hi Rebekah!

It is definitely valid. I've attached a couple of recent papers that use the framework…you should be able to find the references there (there are many papers out there that use this approach). If you want to send a spreadsheet along, I'd be happy to look it over. Time is tight at the moment (an 8th grade graduation and a high school graduation) and I'll be out next week, but should be around much of the summer.

Terri

From: Rebekah Reid <rebekah_reid@fws.gov>
Sent: Wednesday, June 13, 2018 10:30 AM
To: Therese Donovan <tdonovan@uvm.edu>
Subject: SMART Analysis and SSAs

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Original Article

Using Structured Decision Making to Manage Disease Risk for Montana Wildlife

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ABSTRACT We used structured decision-making to develop a 2-part framework to assist managers in the proactive management of disease outbreaks in Montana, USA. The first part of the framework is a model to estimate the probability of disease outbreak given field observations available to managers. The second part of the framework is decision analysis that evaluates likely outcomes of management alternatives based on the estimated probability of disease outbreak, and applies managers' values for different objectives to indicate a preferred management strategy. We used pneumonia in bighorn sheep (*Ovis canadensis*) as a case study for our approach, applying it to 2 populations in Montana that differed in their likelihood of a pneumonia outbreak. The framework provided credible predictions of both probability of disease outbreaks, as well as biological and monetary consequences of management actions. The structured decision-making approach to this problem was valuable for defining the challenges of disease management in a decentralized agency where decisions are generally made at the local level in cooperation with stakeholders. Our approach provides local managers with the ability to tailor management planning for disease outbreaks to local conditions. Further work is needed to refine our disease risk models and decision analysis, including robust prediction of disease outbreaks and improved assessment of management alternatives.

KEY WORDS bighorn sheep, disease, Montana, *Ovis canadensis*, proactive management, structured decision-making.

Infectious diseases in wildlife are increasing, posing significant threats to the health of wildlife, domestic animals, and human populations and conservation of biodiversity (Daszak et al. 2000). Some of these diseases can result in massive die-offs of wildlife (Young 1994) or in significant commercial losses to livestock operations (e.g., brucellosis; Corbel 1997). Wildlife managers are generally poorly prepared to manage disease outbreaks proactively, relying instead on reactive "crisis management" (Woodroffe 1998). Deem et al. (2001) recommended that disease management for wildlife comprise health surveys, long-term monitoring, and interdisciplinary research, but did not specify how information obtained through such a program could be used to make management decisions. Decker et al. (2006) provided a model for making proactive decisions on wildlife disease management based on public and professional perceptions but did not link the model directly to a process for monitoring or predicting disease outbreaks. Biologists have used decision analysis tools to link estimated probability of disease outbreaks explicitly to decisions for managing endangered species (e.g., Maguire et al. 1987), but to our knowledge this methodology has not been applied to managing disease or its consequences in state-managed wildlife populations.

The purpose of this paper is to present a preliminary, structured decision-making framework (Keeney 2007, Gregory et al. 2012) developed for Montana Fish, Wildlife, and Parks (USA) for discerning the trade-offs of managing disease outbreaks proactively or reactively. The approach comprises 1) estimating the likelihood of a disease outbreak based on information available to managers, and 2) estimating the outcomes of management alternatives, given estimated probabilities of disease outbreak. Structured deci-

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sion-making is a transparent, stepwise process for making complex decisions that includes 1) identifying the problem to be solved, 2) determining fundamental objectives that will be used to evaluate how management actions address the problem, 3) defining alternative management actions, 4) estimating consequences for each management action based on fundamental objectives, and 5) identifying the management alternative that provides the best outcome or combination of consequences (Hammond et al. 1999). Below, we present the results of each step of the structured decision-making process.

PROBLEM STATEMENT

Montana Fish, Wildlife, and Parks has direct experience with wildlife disease events that have affected wildlife conservation and public enjoyment of wildlife resources. For the most part, Montana Fish, Wildlife, and Parks has only reacted to these major disease events and currently has no tools for determining whether taking actions to proactively prevent similar events will produce more desirable results. Future wildlife disease issues in Montana are unavoidable. Montana Fish, Wildlife, and Parks wildlife managers and biologists need risk assessment and decision analysis tools to help prioritize and allocate resources to identify and manage the risk of major disease events. These tools need flexibility in their implementation so that decisions about wildlife management and conservation remain local and community-based.

We structured our decision analysis to reflect the agency structure, the fact that wildlife diseases affect populations of particular species in particular areas, and that 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. In practice, 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 in Montana, but can be generalized into statewide categories of aggressive proactive actions, moderate proactive actions, and reactive actions (i.e., 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 in Montana. A set of models to predict the consequences of management actions on specific wildlife species and health issues, however, can be developed to assist in making those local and regional predictions. Employing these models across Montana using the common framework presented here will facilitate a consistent approach to the way in which local wildlife health management decisions are made. In addition to site-specific consequence predictions, value weights for objectives, trade-offs, and risk tolerance are likely to be specific to each regional wildlife biologist or program manager with responsibility for a particular population of wildlife.

FUNDAMENTAL OBJECTIVES

We identified a set of nested objectives and sub-objectives that are fundamental for a general, proactive wildlife health program in Montana:

1. Maximize wildlife population health, which includes 2 sub-objectives: maximize the probability of population persistence and minimize the probability of a disease outbreak occurring that leads to a major die-off of a wildlife population.
2. Minimize risks posed by wildlife, which includes sub-objectives to minimize risk of disease transmission to livestock and to people.
3. Minimize costs, including sub-objectives to minimize operating costs, personnel costs, and other costs associated with responding to crises.
4. Maximize public satisfaction, which includes sub-objectives to maximize both non-consumptive and hunting opportunities.

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.

To illustrate the decision structure and how the overarching Montana wildlife health program might be applied, we used pneumonia outbreaks among bighorn sheep (*Ovis canadensis*) populations as a case study for working through our decision analysis. Outbreaks of pneumonia in bighorn sheep are commonly tied to contact with domestic sheep and goats and can result in catastrophic die-offs (Foreyt and Jessup 1982, Foreyt 1989, Cassirer and Sinclair 2007, Wehausen et al. 2011). Recently, pneumonia has resulted in large die-offs within populations of bighorn sheep across the western United States, at times necessitating extensive culling efforts in an attempt to control spread of the disease. These die-offs have led to the loss of individual populations and, in some instances, meta-populations (Edwards et al. 2010). Our decision analysis begins to fulfill the management need for establishing a systematic health-monitoring and disease management program identified in the Montana Bighorn Sheep Conservation Strategy (MFWP 2009). For application to management of pneumonia outbreaks in bighorn sheep, we narrowed the objectives to reflect the management context unique to bighorn sheep:

1. Maximize the probability of herd persistence, which we propose to measure by determining whether populations are within objectives or not, as defined by the Montana Bighorn Sheep Conservation Strategy (MFWP 2009). The persistence of populations depends on social tolerance as much as biological carrying capacity and stochastic persistence risks associated with small populations; Montana Fish, Wildlife, and Parks has already established population objectives that consider these factors.

2. Minimize costs, including operational costs, personnel costs, and crisis response costs. We will measure this objective using projected 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.

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. 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, alternatives focus on the relative effort invested in maintaining physical separation of bighorn sheep and domestic sheep and goats. Possible actions managers and biologists could take to manage a major disease event fall within 3 categories:

1. *Reactive management actions*. This involves no attempt to proactively limit interactions between wild and domestic sheep and goats. Population declines lead to populations failing to meet defined objectives, allocation of staff time and resources to cull (if appropriate) sick bighorn sheep, collecting and processing biological samples, sample analysis fees, increased monitoring to detect recovery of collapsed populations, as well as the loss of viewing and hunting opportunities.
2. *Moderate proactive management actions*. These actions will be relatively low-cost and socially acceptable, specific to local circumstances, and the situation as determined by regional wildlife managers and biologists. These may include communicating with landowners or livestock producers to minimize contact between bighorn sheep and domestic sheep or goats, or removing bighorn sheep that commingle with domestics.
3. *Aggressive proactive management actions*. These actions will be more expensive, potentially less socially acceptable, and, again, specific to local circumstances. Actions may include fencing domestic sheep herds to limit interactions between bighorn sheep and domestic sheep or goats, or increasing male bighorn sheep harvest in order to effect a decline in the adult male:adult female ratio (thereby preventing the spread of disease by wide-ranging males during the rut).

PREDICTING THE LIKELIHOOD OF A MAJOR DISEASE EVENT

Development of predictive models for the risk of wildlife disease events would help wildlife managers in their decision-making processes. Predictive 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 site-specific management options.

To illustrate this, we developed a risk assessment model to predict the probability of a major disease event for a herd of bighorn sheep over a 10-year time horizon. We defined a major disease event as one with $\geq$50% mortality in any 1 year. The model was simple (Table 1): the probability (Pr) of a major disease event in any 1 year was a function of Pr(exposure), E; Pr(susceptibility), S; and Pr(risk of spread), R.

For our case study, we assumed E 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 cue reflected a subjective, relative weighting of importance as decided upon by the experience and expertise of our team. We defined E as the sum of the assigned values for each cue, divided by the maximum possible value for the sum (Table 1).

We assumed S could be predicted by the unweighted average of several cues, including assessments of clinical condition, habitat condition, and low recruitment of lambs (lamb mortality is high during and following pneumonia outbreaks). We estimated S as the average value (range = 0–3) assigned to each of 6 potential indicators, divided by 3, the maximum possible value for the average. Indicators for which no information was available did not contribute to the average (Table 1).

We assumed R could be predicted by the density and distribution of bighorn herds, and the observed ratio of adult males to adult females (males range much more widely than females and are thought to be important vectors for spread of disease among herds). We defined R as the sum of the assigned values for each, divided by 9, the maximum possible value for the sum (Table 1).

We defined the Pr(major disease event in any 1 yr) as the product of E, S, and R. The probability of *no* major disease event in t years is $1 - \text{Pr(major disease event in any 1 yr)}^t$. Over a time horizon of 10 years, the probability of observing at least one major event was $1–[1 - \text{Pr(major disease event in any 1 yr)}]^{10}$ (Mood et al. 1974).

Our model was constructed in a spreadsheet so that regional wildlife biologists and managers could use it to 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

Table 1. Disease risk model for estimating the probability of a major disease outbreak (i.e., ≥50% mortality in a population) for bighorn sheep (*Ovis canadensis*) in Montana, USA, based on estimated exposure, E, susceptibility, S, and risk of spread, R. Annual risk of a major disease outbreak $= E \times S \times R$.

Metric	Score[a]
Risk of exposure, E	If $E2 = 8$, then $E = 1$, else $E = \frac{\sum(E1, E2, E3)}{\sum(E1^{max}, E2^{max}, E3^{max})}$
Contact with domestic sheep and goats, $E1$	
Highly unlikely	0
Within range of forays	2
Within ≤7 miles	4
Within home range	6
Contact with infected bighorn sheep, $E2$	
Highly unlikely	0
Within range of forays	2
Within adjacent herd	4
Within home range	8
Current presence of pathogens, $E3$	
Absent or unknown	0
Present in the past	1.5
Known to be present	3
Susceptibility, S	$S = \frac{\sum(S1, S2, S3, S4, S5, S6)/6}{3}$
Body condition, $S1$	Low (0), medium (1.5), high (3)
Parasite load, $S2$	Low (0), medium (1.5), high (3)
Blood parameters, $S3$	Low (0), medium (1.5), high (3)
Range measures, $S4$	Low (0), medium (1.5), high (3)
Mineral levels, $S5$	Low (0), medium (1.5), high (3)
Lamb:F ratio, $S6$	Poor (3), low (2), medium (1), high (0)
Risk of spread, R	$R = \frac{\sum(R1, R2, R3)}{\sum(R1^{max}, R2^{max}, R3^{max})}$
Herd density, $R1$	
Within Montana Fish, Wildlife, and Parks objectives	0
Slightly over Montana Fish, Wildlife, and Parks objectives	1.5
Well over Montana Fish, Wildlife, and Parks objectives	3
Herd distribution, $R2$	
Normal-sized herds	0
Large herds, small natural areas	1.5
Large herds, small artificial areas	3
M:F ratio, $R3$	Low (0), medium (1.5), high (3)

[a] Scores assigned to sub-metrics are based on subjective evaluation of relative contribution to overall risk of disease outbreak.

uniform tool for managers to assess and compare alternative, local management actions and to engage stakeholders in the decision process.

To evaluate the usefulness of this model in informing management decisions, we parameterized the model for the Missouri Breaks bighorn sheep herd in eastern Montana and the Petty Creek bighorn sheep herd in western Montana (Fig. 1). We chose these herds because the herd managers were present on our team, and because they represented different disease contexts in different parts of Montana. We parameterized the model for the 3 management alternatives (reactive 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 regarding clinical and habitat conditions. We elicited values for calculating E, S, and R under the assumption they equated with relative probabilities.

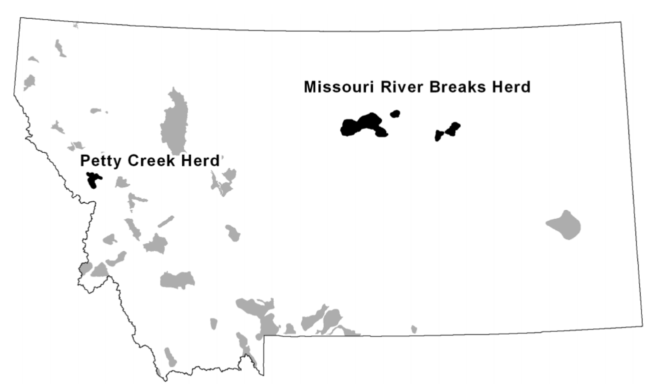

Figure 1. Locations of bighorn sheep (*Ovis canadensis*) herds in Montana, USA. Darkened polygons represent the Petty Creek herd in western Montana, and the Missouri Breaks herd in central Montana. The 2 herds experience 2 different environments affecting likelihood of major disease outbreak. The Petty 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.

DECISION ANALYSIS

For both the Missouri Breaks and Petty Creeks herds, we constructed a decision tree (Behn and Vaupel 1982; Table 2) to estimate the consequences of the 3 management alter-

Table 2. Example of a decision table with estimated consequences for 3 alternative strategies for managing disease outbreak in bighorn sheep (*Ovis canadensis*) within the next 10 years proactively, illustrated for a population of bighorn sheep living in Petty Creek, Montana, USA. The top row contains fundamental objectives, the second row contains whether objectives were to be minimized or maximized, the third row contains measurable attributes for each objective, and the fourth row the scale on which they are measured. The remaining 3 rows contain the estimated consequences under each objective in the event a major disease outbreak does and does not occur, and the "expected" or the probability-weighted average outcome, under each of the 3 management alternatives (Behn and Vaupel 1982). Probabilities of disease or no disease are estimated from the disease risk model in Table 1.

Management alternative	Fundamental objective:	Probability of persistence	Operating costs	Personnel costs	Crisis response	Viewing opportunity	Hunting opportunity
	Goal:	Maximize	Minimize	Minimize	Minimize	Maximize	Maximize
	Attribute:	Meet population objective?	US$ cost/ 10 yr	Person-days/ 10 yr	US$ cost/ 10 yr	Meet population objective?	No. licenses sold/10 yr
	Scale:	1 = yes, 0 = no	US$K/10 yr	Days	US$K/10 yr	1 = yes, 0 = no	No./10 yr
Aggressive, proactive	Pr(disease) = 0	0	105	220	80	0	100
	Pr(no disease) = 1.0	1.0	105	220	0	1.00	200
	Expected outcome[a]	0.9	105	220	8	0.90	190
Moderate, proactive	Pr(disease) = 0.2	0	100	170	80	0	75
	Pr(no disease) = 0.8	1.0	100	170	0	1.00	150
	Expected outcome	0.8	100	170	16	0.80	135
Reactive	Pr(disease) = 0.6	0	0	0	80	0	75
	Pr(no disease) = 0.4	1.0	0	0	0	1.00	150
	Expected outcome	0.4	0	0	48	0.40	105

[a] Expected outcome = [consequence of disease × Pr(disease)] + [consequence of no disease × Pr(no disease)].

natives. Probabilities describing the chance of 2 possible states—the occurrence or non-occurrence of a major disease event within 10 years—were used to estimate "expected consequences," or the average of the consequences with and without disease weighted by the probability of whether a major disease event would occur under each management alternative (Table 2). Then we used these expected or probability-weighted outcomes to assess the managers' preferences for balancing between their objectives, using the Simple Multi-Attribute Rating Technique (Edwards 1971, Goodwin and Wright 2004). For both herds, we normalized the expected consequences across the range in our alternatives for each objective and weighted them according to the value judgments of these local bighorn sheep herd managers, elicited using swing weighting (von Winterfeldt and Edwards 1986). We then aggregated judgments using simple weighted summation to characterize the overall value of each alternative (Table 3).

Our analyses for the Petty Creek and Missouri Breaks herds provided a good test of the ability of this decision

Table 3. Example of a Simple Multi-Attribute Rating Technique decision analysis evaluating 3 management alternative to proactively managing disease outbreak in bighorn sheep (*Ovis canadensis*; no proactive management, moderate proactive management, and aggressive proactive management), illustrated for a population of bighorn sheep living in Petty Creek, Montana, USA. 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, estimated by swing weighting based upon the range of expected outcomes for each objective (Table 2). Weights were determined subjectively by decision-makers and sum to 1. The final 9 rows contain the expected outcomes, their normalized score, and their weighted score for each of the fundamental objectives under each of the 3 management strategies and in the last column the sum of normalized, weighted scores, indicating relative support of the decision analysis for each management alternative (Goodwin and Wright 2004).

Management alternative	Fundamental objective:	Probability of persistence	Operating costs	Personnel costs	Crisis response	Viewing opportunity	Hunting opportunity	Summed normalized, weighted scores
	Goal:	Maximize	Minimize	Minimize	Minimize	Maximize	Maximize	
	Measurable attributes:	Meets population objective?	US$ cost/ 10 yr	Person-days/ 10 yr	US$ cost/ 10 yr	Meets population objective?	No. licenses sold/10 yr	
	Weight:	0.21	0.15	0.14	0.19	0.15	0.18	
Aggressive, proactive	Expected outcome[a]	0.9	105	220	8	0.9	190	
	Normalized score	1.00	0.00	0.00	1.00	1.00	1.00	
	Weighted normalized score	0.21	0.00	0.00	0.19	0.15	0.18	0.72
Moderate, proactive	Expected outcome	0.8	100	170	16	0.8	135	
	Normalized score	0.80	0.05	0.23	0.80	0.80	0.35	
	Weighted normalized score	0.17	0.01	0.03	0.15	0.12	0.06	0.53
Reactive	Expected outcome	0.4	0	0	48	0.4	105	
	Normalized score	0.00	1.00	1.00	0.00	0.00	0.00	
	Weighted normalized score	0.00	0.15	0.14	0.00	0.00	0.00	0.28

[a] From Table 2.

analysis system to assist managers in making decisions. The 2 herds experience very different environments affecting the likelihood of disease outbreaks. The Petty Creek herd is at a high-risk of exposure 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 disease risk model and decision analysis tools 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.

Given input by species experts and managers and assuming current management practices continue, the risk analysis model predicted the probability of a major disease event within the next 10 years to be 0.56 for the Petty Creek herd and 0.18 for the Missouri Breaks herd. 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 (Table 3; Fig. 2). By contrast, the analysis for the Missouri Breaks herd showed strong support for either aggressive or moderate proactive management, with little support for reactive management (Fig. 2).

DISCUSSION

To facilitate the development of a wildlife health program for the state of Montana, we used a structured decision-making approach to define the problem, establish fundamental objectives, identify alternative management actions, and define metrics of success. During this process we developed a model to estimate the probability of a disease outbreak and linked this model with decision analysis that allows managers to proactively evaluate likely effects of alternative actions on both disease risks and fundamental management objectives. Carefully structuring the analysis led to substantial progress that would not have been possible otherwise. The major value of this approach came from the focused thinking and debate on the problem statement, the objectives of the program, 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 centralized decision-making authority. This clarity would not have been possible without carefully delineating the various elements of the actual decision.

We designed a framework that assists regional managers in reaching local decisions reflecting statewide wildlife conservation objectives. The framework we developed addresses 2 of the most challenging components of decision-making in wildlife conservation and disease management in particular: the inherently probabilistic nature of disease events and effects, and the inherent tensions among Montana Fish, Wildlife, and Parks's fundamental objectives. To this end, we employed a combination of modeling and decision analysis tools, including a predictive risk model, a decision tree, and Simple Multi-Attribute Rating Technique trade-off analysis and management alternatives scoring.

Although we have explored the value of the more technical aspects of this decision framework (e.g., models used to predict the consequences of alternative management actions relative to meeting objectives), their full potential has not yet been fully realized. To use the model we developed for predicting the risk of major disease events in bighorn sheep herds to inform decisions about bighorn sheep management, more focused work on model development and reliability is required. This technical work is appropriate 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 help managers make decisions that are better for having used the models than they would have been otherwise. Work to increase the accuracy of predictive models is warranted if it improves the decision analysis, affecting not only the consequence predictions but the indicated choice among management options and confidence those actions will achieve management's fundamental objectives.

In our bighorn sheep model, for example, the measurable attributes relative to the population objectives are likely oversimplified. 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 fall marginally outside objective bounds are thus assigned zero value, which may prove unrealistically simple for assessing trade-offs that wildlife managers need to make. In future application, the attribute may

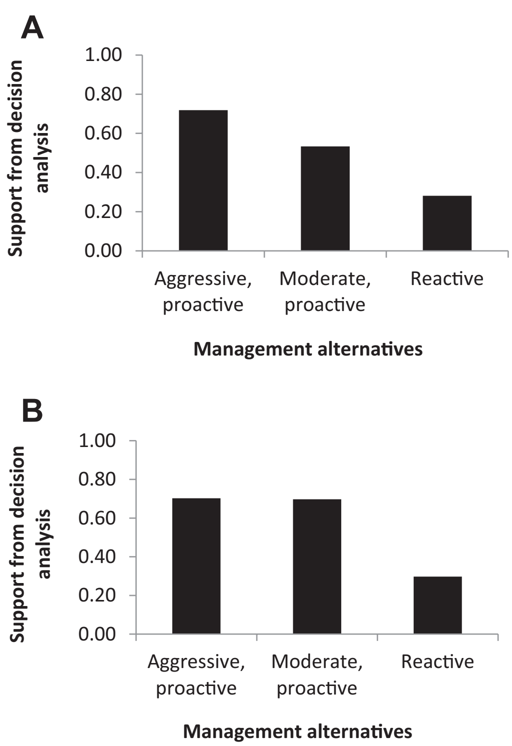

Figure 2. Results of decision analyses for disease management in the Petty Creek (A) and Missouri Breaks (B) herds of bighorn sheep (*Ovis canadensis*) in Montana, USA. Graphs illustrate relative support for the 3 management alternatives between the 2 herds.

be constructed such that all population sizes within objective bounds receive the highest possible value, while population sizes outside of the objective range are scored lower the further from the objective bounds they are (*sensu* Keeney 2007). Similarly, we used population objectives as measurable attributes for 2 fundamental objectives; future application should identify a distinct and more focused attribute for public satisfaction instead of duplicating the population persistence attribute. This should allow managers the flexibility needed to make trade-offs in management decisions when necessary.

Uncertainty within the risk analysis model also needs to be addressed. The illustrative model we developed for bighorn sheep is a simple linear additive model built on expert judgment, which although generally robust to uncertainty (Dawes 1979, Dana and Dawes 2004), could be improved substantially. 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 do the following:

1. Coordinate with other experts in Montana to ensure all of the key factors influencing probabilities of pneumonia outbreaks are captured in the modeling framework, and factors used to predict probabilities of pneumonia outbreaks are measured and weighted relative to each other in an epidemiologically credible manner.
2. Use statistical model(s) to predict disease outbreaks using the available historical data, in order to 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 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. The sensitivity analysis needs to reveal the extent to which these critical assumptions affect overall predictions of the probability of disease outbreaks and resulting choice of preferred management actions. The sensitivity analysis can inform how much effort is warranted toward improving the models, including identifying more nuanced and accurate relationships between risk and exposure than the simple linear relationship assumed in the case study.
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 these tools are used to inform decisions.

Ultimately, the Montana wildlife health program must be structured as the agency is structured. To be effective and sustainable it should be fully integrated into the broader wildlife conservation program via a focus on unifying wildlife conservation objectives. The overall mission 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. This context is imperative because the mission of state and federal wildlife agencies is more focused on fundamental wildlife conservation objectives than on elimination or limitation of wildlife disease. By using this framework, undesirable consequences of wildlife disease for effective wildlife conservation need to be identified before resources are expended to manage disease transmission or monitor the disease. Undesirable consequences of wildlife disease are not necessarily universal, for example parasites and diseases can have fundamental roles in ecosystem function (Eviner and Likens 2008), and in many cases the ecological consequences of diseases are virtually unknown (Deem et al. 2008). In addition, some actions designed to limit disease spread will require trade-offs for objectives valued for other aspects of wildlife conservation (e.g., reductions in wildlife population sizes). Without placing a wildlife health program in a decision analysis context such as Simple Multi-Attribute Rating Technique, such trade-offs could not be made explicit. Objectives may 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.

Both the disease risk model and decision analysis tools 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 expanded to encompass diseases such as brucellosis, chronic wasting disease, etc., and other wildlife species that are affected by health issues. Whereas 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.

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Research Article

Addressing Wild Turkey Population Declines Using Structured Decision Making

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ABSTRACT We present a case study from New York, USA, of the use of structured decision making (SDM) to identify fall turkey harvest regulations that best meet stakeholder objectives, in light of recent apparent declines in abundance of wild turkeys in the northeastern United States. We used the SDM framework to incorporate the multiple objectives associated with turkey hunting, stakeholder desires, and region-specific ecological and environmental factors that could influence fall harvest. We identified a set of 4 fall harvest regulations, composed of different season lengths and bag limits, and evaluated their relative achievement of the objectives. We used a stochastic turkey population model, statistical modeling, and expert elicitation to evaluate the consequences of each harvest regulation on each of the objectives. We conducted a statewide mail survey of fall turkey hunters in New York to gather the necessary information to evaluate tradeoffs among multiple objectives associated with hunter satisfaction. The optimal fall harvest regulation was a 2-week season and allowed for the harvest of 1 bird/hunter. This regulation was the most conservative of those evaluated, reflecting the concerns about recent declines in turkey abundance among agency wildlife biologists and the hunting public. Depending on the region of the state, the 2-week, 1-bird regulation was predicted to result in 7–32% more turkeys on the landscape after 5 years. The SDM process provided a transparent framework for setting fall turkey harvest regulations and reduced potential stakeholder conflict by explicitly taking the multiple objectives of different stakeholder groups into account.

KEY WORDS decision analysis, harvest regulations, management, *Meleagris gallapavo*, New York, population model, structured decision making, wild turkey.

In the northeastern United States, spring wild turkey (*Meleagris gallapavo*) harvest steadily increased in the 1990s but more recently either has declined (Mid-Atlantic states) or the rate of increase has slowed (New England states; Casalena et al. 2016). The concurrent observed declines in reproductive success in the northeastern United States indicate that turkey abundance has decreased from a peak that was reached during restoration (Casalena et al. 2016). The apparent decline in turkey abundance potentially could be slowed or reversed through implementation of management actions. For example, habitat management activities could be designed to increase recruitment and adult female survival in the breeding season (Jimenez and Conover 2001, Casalena et al. 2007, Fuller et al. 2013), and changes in fall harvest regulations could reduce harvest of females and offset the decline in abundance. Spring harvest is the greatest source of mortality for male turkeys (Godwin et al. 1991, Paisley et al. 1996, Wright and Vangilder 2005, Diefenbach et al. 2012), but the fall either-sex turkey harvest has a greater effect on population dynamics because harvest of females in the fall is greater than in the spring (Vangilder and Kurzejeski 1995, Alpizar-Jara et al. 2001, McGhee et al. 2008, Stevens et al. 2016). Re-evaluating fall turkey harvest regulations is an appropriate first step to take to mitigate the apparent decline in turkey abundance because of the

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potential ability of reductions in female harvest to offset the apparent declines in abundance (Vangilder and Kurzejeski 1995, Alpizar-Jara et al. 2001, McGhee et al. 2008, Stevens et al. 2016), and because these regulations can be changed with relative ease.

Despite the potential for mitigating apparent declines in turkey abundance, fall harvest regulations involve many social and ecological considerations that increase the complexity of the decision. Complex tradeoffs to consider include turkey population dynamics and the associated uncertainties in turkey demographic rates, stakeholder desires (e.g., hunting opportunity), and management zone-specific environmental factors that influence fall turkey harvest and population demographics (e.g., land cover and land use [Porter and Gefell 1996], spring weather [Porter and Gefell 1996], and winter severity [Porter et al. 1980, Vander Haegen et al. 1989]). Explicit incorporation of stakeholder values as elicited directly from stakeholders, in addition to ecological values, would allow for consideration of diverse objectives inherent in harvest management decisions. Any potential harvest regulations could be evaluated in terms of the entire set of objectives, and a formal evaluation of the tradeoffs subsequently can be made among those objectives.

Structured decision making (SDM) provides a framework that can incorporate the multiple objectives and tradeoffs associated with management decisions, such as those inherent to turkey management. The goal of the SDM process is to aid authorities responsible for management action by providing insight and information about the decision, including the multiple objectives of different stakeholder groups, key uncertainties, and important tradeoffs (Clemen 1996, Gregory et al. 2012). The SDM process guides decision maker(s) through the steps of defining the problem, determining all relevant objectives, identifying a set of management actions, predicting the effect of each management alternative on the objectives, and evaluating the tradeoffs that must be made among objectives (Hammond et al. 1999, Gregory et al. 2012). The SDM process separates values, in the objectives and tradeoffs stages, from science, in the consequences stage. This problem decomposition results in a management decision that is values-driven (i.e., focused on stakeholders' values; Keeney 1992), explicitly incorporates uncertainty (Runge 2011, Moore and Runge 2012), and transparent, in the sense that it improves communication about the manner in which the decision was made (Gregory and Keeney 2002). Because stakeholders can see how their concerns are incorporated into the decision, and how well each management action achieves their objectives, the optimal decision often garners more support from stakeholder groups than decisions made with a less transparent process (Decker et al. 2012, Riley and Gregory 2012) or those that lack a formal evaluation of the different alternatives.

We use New York, USA, as a case study to demonstrate how an SDM framework can identify management zone-specific fall turkey harvest regulations that would best achieve multiple stakeholder objectives, while taking into account key uncertainties and tradeoffs. The ecological and social aspects of this management decision required the type of problem decomposition inherent in SDM. Tradeoffs included those between objectives related to hunter satisfaction and reducing the declines in turkey abundance. Multiple dimensions of experience affect hunters' perceptions of a satisfying turkey hunting experience (Hazel et al. 1990, Siemer et al. 1995, Wynveen et al. 2005). Wildlife agencies are challenged to address multiple, sometimes competing, hunter objectives. For example, hunter surveys indicate that seeing and hearing turkeys and having ample opportunities to harvest turkeys contribute to hunting satisfaction for substantial numbers of turkey hunters (Siemer et al. 1995, Wynveen et al. 2005), but seeing or hearing turkeys and expanding opportunities to harvest turkeys are management objectives that could be in conflict (i.e., achieving one of those objectives may compromise ability to achieve the other). Our research addressed wildlife managers' uncertainty regarding what factors contributed to hunter satisfaction with current fall turkey hunting opportunities and about potential causes of a decline in fall turkey hunter effort. We implemented a statewide survey of fall turkey hunters to identify how hunters value these multiple dimensions of satisfaction, determine whether these values differed among regions of the state, and alleviate uncertainties about hunter satisfaction. Additionally, we evaluated uncertainty in the demographic responses of turkeys in 3 newly delineated management units to changes in fall season structure and the effects of ecological factors on turkey survival and harvest. This project required the cooperation of scientists and managers of the state wildlife agency, social scientists and ecologists from academia, and decision analysts and ecologists from the federal government. The ranges of stakeholder values and data necessary to make informed and robust decisions for natural resources management required a multi-disciplinary approach, and SDM effectively used these collaborations. Through the SDM process, we provided a framework for the state agency to take the various considerations into account and make a decision about how best to manage fall turkey harvest.

STUDY AREA

Our study area was the state of New York (74,576 km^2, elevation range 0 to >1,500 m), which is divided into 6 climate regions that experience a range of temperatures and precipitation patterns across the seasons (Thompson 1996, Bowling 2014). New York's landscape includes ecoregions that range from evergreen forests in the Adirondack region, to flat landscapes with many wetlands in the St. Lawrence Plain and Champlain Valley, to agriculturally dominated landscapes in the western part of the state (Bailey 1995, Bowling 2014). We divided our study area into turkey management zones (TMZs), defined based on similarities in turkey demographics and landscape characteristics (Bowling 2014). Each TMZ contained multiple wildlife management units (Fig. 1), the geographic unit of management that the New York State Department of Environmental Conservation (NYSDEC) used to set hunting regulations for multiple wildlife species. We did not evaluate fall harvest regulations

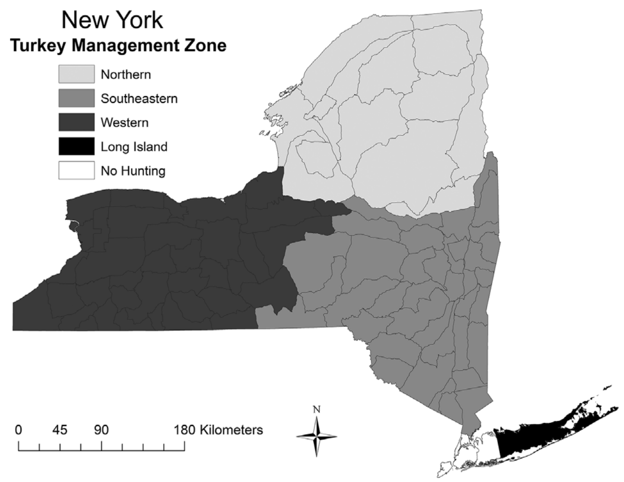

Figure 1. Four turkey management zones in New York, USA. Lines represent wildlife management units for New York.

for the Long Island TMZ (619 km^2), where the current fall season (1 week, 1 bird) was the shortest in the state. Although biological and social data for this region were limited, measures of abundance from surveys and the existing hunting season indicated that turkey densities in Long Island were similar to or greater than portions of upstate New York that have similar or longer hunting seasons. In addition, hunting pressure in Suffolk County was lower than in the rest of the state. Based on the limited data on turkey abundance and hunting participation and effort in Suffolk County, we applied the most conservative outcome from the analysis of the other 3 turkey management zones to the Long Island zone.

METHODS

The management decision was decomposed into the problem, objectives, alternatives, consequences, and tradeoffs (PrOACT; Hammond et al. 1999). The problem statement contained the background to establish the fundamental and means objectives of the decision problem. Fundamental objectives define what the decision makers fundamentally value, whereas means objectives provide a pathway for achieving those fundamental objectives (Keeney 1992). We used these objectives to guide the creation a set of management alternatives for fall turkey harvest regulation. We created a population model to evaluate the effect of each management alternative on turkeys in each TMZ. We used a multi-attribute utility function that included the results of the population model, expert opinion, and stakeholder values, to determine the management strategy that best achieved the multiple objectives.

Problem Statement

The problem statement, which guides the rest of the decision process (Hammond et al. 1999), contained information about the most important factors for the decision about fall turkey hunting season structure in New York, the ultimate decision maker, and spatial and temporal aspects of the problem. The decision maker was the Commissioner of NYSDEC, with agency staff representing the delegated authority for this decision. We developed a working group of NYSDEC biologists and managers, natural resource professionals (NYSDEC, Pennsylvania Game Commission [PGC]), experts in social science (Cornell University), and experts in decision analysis (United States Geological Survey [USGS], Cornell University) and wild turkey management (USGS, PGC, NYSDEC; 10 people in total). The working group expressed concerns related to perceived declines in turkey abundance and uncertainty about hunter attitudes and opinions. Managers also stated that, in light of the concerns about the apparent decline in turkey abundance informally expressed by turkey hunters, a more structured and transparent process for setting regulations that allowed for a formal evaluation of the alternative management regulations was important for stakeholder support of any new regulations. The stated goal for harvest management was to provide a sustainable wild turkey population to provide optimal opportunities for hunters and others to enjoy the wild turkey resource now and in the future, while being sensitive to potential negative impacts of fall turkey hunting on turkey population growth. The problem statement recognized that simultaneously maximizing abundance of turkeys and hunting opportunity was not possible (hence, the use of the word optimal) and provided the relevant information to develop a set of fundamental objectives for the decision analysis.

Objectives

We developed the fundamental objectives in a hierarchy, reflecting the values of the state wildlife management agency, the hunting public, and others who value turkeys (e.g., bird watchers or those who enjoy seeing turkeys). Two overarching fundamental objectives described the values of the stakeholders, as determined by the working group: maximize the turkey population and maximize hunter satisfaction. Given the focus on fall harvest regulation for managing turkey abundance, the turkey population would be maximized through the means objective of minimizing female mortality due to fall hunting. We measured the turkey population objective as the predicted number of turkeys on the landscape in a given TMZ just prior to spring harvest, relative to the number under current regulations (status quo). Status quo regulations in New York consisted of a season length from 1 to 6 weeks and a bag limit of 1 or 2 turkeys, depending on the region of the state.

We created a set of fundamental objectives for hunter satisfaction based on research that described various components of hunter satisfaction (Hendee 1974, Decker et al. 1980, Hammitt et al. 1990, Enck and Decker 1991, Siemer et al. 1995). We used research about hunter satisfaction and the expert opinion of the working group to create the objectives in lieu of working directly with hunting groups. Although hunters were not included in the creation of objectives, we created a hunter survey (see below) to allow hunters to express how they value each of these components of hunter satisfaction. We established 5 objectives and their associated performance measures.

1. Minimize conflicts with other hunters (turkey or other game). Hunter conflict refers to a potential decrease in satisfaction as hunter density on the landscape increases. We measured hunter conflict as a constructed attribute. A constructed attribute is a scale of measure that is created specifically for a decision context (Keeney 1992). In this case, the constructed attribute was a 0–1 utility scale in which 0 = the regulation that produces the least amount of conflict and 1 = the regulation that produces the most amount of conflict, with intermediate values representing intermediate levels of conflict.
2. Maximize fall hunting opportunity. We measured hunting opportunity as the season length and the number of turkeys that each hunter legally was allowed to harvest during the season (bag limit).
3. Maximize fall observations of turkeys. Seeing turkeys can be inhibited by environmental factors, such as high levels of mast that would disperse turkeys across the landscape or cluster turkeys in areas that are not available for hunting (Steffen et al. 2002). Therefore, the perception of the availability of harvestable turkeys can differ from the actual number of turkeys on the landscape. We measured fall observations as the predicted number of turkey observations made by white-tailed deer (*Odocoileus virginianus*) archery hunters (bow hunter sighting index) just prior to the fall hunting season.
4. Maximize fall harvest opportunity. We measured harvest opportunity as the predicted number of turkeys on the landscape, relative to the number available under current regulations, just prior to fall harvest.
5. Maximize fall harvest success. We measured harvest success as the expected number of turkeys harvested, relative to the number harvested under current regulations.

Alternatives

We developed a finite set of regulations, or alternatives, to achieve the stated objectives. Although we could have identified an infinite number of regulations, we wanted a small, discrete set that we expected to differ measurably in their ability to satisfy the various objectives. In addition, the group considered only regulations that would be viable for implementation (e.g., a total closure of the fall season would not be considered or implemented by the state). The working group considered 4 possible regulations that were combinations of season length (2–7 weeks) and bag limit (1–2 birds) thought to best achieve the fundamental objectives. The regulations considered were 2-week season and 1-bird limit, 3-week season and 1-bird limit, 4-week season and 2-bird limit (1 bird/day), and 7-week season and 2-bird limit. The group thought that these 4 regulations could best achieve each of the fundamental objectives or might perform best when tradeoffs were made among these objectives.

Consequences

Consequences predict the relative achievement of each objective by each alternative. We used output from a turkey population simulation model, linear modeling of fall turkey sighting data collected by NYSDEC, and expert opinion to predict the consequences of each alternative on each of the fundamental objectives (maximize turkey population size, maximize fall harvest success, maximize fall harvest opportunity, minimize conflicts with other hunters, maximize fall observations of turkeys).

Population model.—We created a stochastic, stage-based simulation model in R (R Core Team 2014) to predict age- and sex-specific fall harvest success (objective: maximize fall harvest success), age- and sex-specific availability of turkeys for fall harvest (objective: maximize fall harvest opportunity), and change in abundance (objective: maximize turkey population size) under the 4 harvest regulation alternatives. We parameterized the model with data from New York and other studies of turkeys in the northern United States (Table 1). The model simulated the population dynamics of poults (<0.4 yr old) and juvenile (<1.4 yr old) and adult (≥1.4 yr old) males and females on an annual cycle (Fig. 2). The output of this population model provided values for the measurable attributes related to turkey abundance and turkey harvest.

The population model began with a pre-spring-harvest density of turkeys that was drawn from a uniform distribution with a TMZ-specific range (Table 1). We chose the range of densities for each zone such that the predicted number of birds harvested in the spring under status quo regulations was similar to actual spring harvest in each TMZ (1999–2012). We calculated the initial number of turkeys (N_o) on the landscape as the initial density multiplied by the area of the TMZ. We divided N_o into males and females by drawing an adult sex ratio (75 M/100 F) from a normal distribution with mean proportion of males = 0.43 and coefficient of variation (CV) = 10% (Hayden and Wunz 1979). The sex-age structure of the simulated population was based on published age structures from tagging studies of females (WI; Rolley et al. 1998) and males (NY; Diefenbach et al. 2012). We calculated the sex- and age-specific initial abundance (N) based on the proportion (Pr) of each sex (i) and age (a; juvenile or adult):

$$N_{i,a,spring} = N_o \times Pr_{i,a}$$

We first subjected male turkeys to spring harvest. We drew spring harvest rates ($\hat{h}$) randomly each year from a uniform distribution of age-specific rates estimated for each TMZ of New York (Diefenbach et al. 2012; Table 1). Harvest of each individual was the product of a Bernoulli trial in which the age-specific harvest rate was the probability of mortality:

$$N_{male,a,summer} = N_{male,a,spring} - binom\left(N_{male,a,spring}, \hat{h}_{male,a,spring}\right)$$

Previous research estimated harvest of bearded females to be <1% in New York (D. R. Diefenbach, U.S. Geological Survey, unpublished data), similar to reported rates in Missouri (Vangilder and Kurzejeski 1995) and Virginia and West Virginia (Alpizar-Jara et al. 2001), so we ignored this source of mortality, such that $N_{female,a,summer} = N_{female,a,spring}$. Following spring harvest, we subjected all remaining turkeys to age- and sex-specific summer mortality. We drew age- and

Table 1. Estimates of all parameters in the turkey population model to predict the consequences of the harvest regulations on the fundamental objectives of maximizing turkey population size, maximizing fall turkey observations, maximizing fall harvest opportunity, and maximizing fall harvest success in New York, USA. Status quo regulations consisted of a season length from 1 to 6 weeks and a bag limit of 1 or 2 turkeys, depending on region of the state.

		Turkey management zone			
Parameter	**Harvest regulation**	**All**	**Northern**	**Southeastern**	**Western**
F fall harvest rate[a,b]	Status quo		0.038–0.093	0.064–0.169	0.045–0.118
	2 weeks, 1 bird		0.017–0.079	0.017–0.079	0.017–0.079
	3 weeks, 1 bird		0.037–0.090	0.037–0.090	0.037–0.090
	4 weeks, 2 birds		0.047–0.116	0.047–0.124	0.047–0.124
	7 weeks, 2 birds		0.064–0.169	0.064–0.169	0.064–0.169
Juvenile M spring harvest[d]	All		0.131–0.141	0.130–0.140	0.163–0.174
Adult M spring harvest[d]	All		0.318–0.361	0.330–0.350	0.388–0.415
Poults/female (SD)[a]	All		2.46 (0.68)	2.71 (0.54)	2.54 (0.47)
Days $\geq$38.1 cm snow (SD)[f]	All		30.79 (19.71)	11.49 (13.83)	5.73 (12.67)
Density (no./miles^2)[a]	All		2.0–4.0	6.9–9.2	9.0–13.0
M fall harvest rate[c]	All	0.090–0.110			
Juvenile F winter survival[b]	All	0.311–0.661			
Adult F winter survival[b]	All	0.570–0.830			
Juvenile M winter survival[d,e]	All	0.891–0.935			
Adult M winter survival[d,e]	All	0.729–0.785			
F summer survival[b]	All	0.604–0.850			
Juvenile M summer survival[d,e]	All	0.907–0.939			
Adult M summer survival[d,e]	All	0.823–0.847			

[a] New York State Department of Environmental Conservation (NYSDEC) data (1997–2012).
[b] D. R. Diefenbach (U.S. Geological Survey, unpublished data).
[c] D. R. Diefenbach (unpublished data).
[d] Calculated from Diefenbach et al. (2012).
[e] Rolley et al. (1998).
[f] NYSDEC data (1988–2013).

sex-specific summer survival rates randomly each year of the simulation from a set of uniform distributions of rates estimated from tagging studies of male turkeys in New York (Diefenbach et al. 2012) and female turkeys in Pennsylvania (D. R. Diefenbach, unpublished data; Table 1). For male turkeys, we calculated the proportion of the annual survival that occurred in each season in a study of male turkeys in Wisconsin (Rolley et al. 1998) and applied that proportional survival to the age-specific annual survival estimates for New York (Diefenbach et al. 2012). Summer survival of each individual was the product of a Bernoulli trial in which the age-specific survival rate ($\hat{s}$) was the probability of survival:

$$N_{i,a,fall} = binom\left(N_{i,a,summer}, \hat{s}_{i,a,summer}\right)$$

We represented productivity in the model as counts of poults per female in August of each year; all females that survived the summer mortality event were included in the estimate of productivity (R). We drew the yearly count of poults/female from a truncated normal distribution with a TMZ-specific mean (μ_r) and standard deviation (σ_r) calculated from August poult count data collected throughout New York State (1997–2012; Table 1):

$$R = N(\mu_r, \sigma_r), \text{where} R \in [0, \infty]$$

We decreased the average number of poults/female in each zone to match the rate of decline in turkey abundance after 5 years of simulation that was observed in any of the TMZs in New York (similar to methods of Alpizar-Jara et al. 2001).

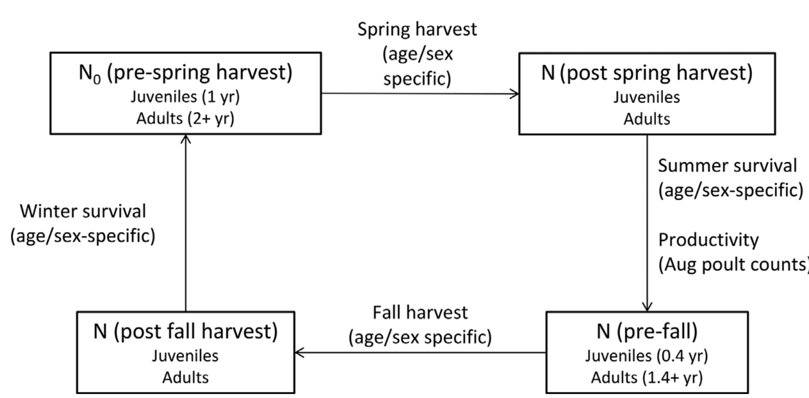

Figure 2. Schematic of the turkey population model used to evaluate the consequences of each harvest regulation on the the fundamental objectives to maximize the turkey population size, maximize fall harvest opportunity, and maximize fall harvest success in New York, USA.

We reduced the average number of poults/female by 0.5 in the Northern zone, 0.45 in the Southeastern zone, and 0.65 in the Western zone. We calculated the number of poults produced in each zone as:

$$N_{poult} = N_{female,summer} \times R$$

with an assumed 50:50 sex ratio of poults.

Following reproduction, poults and juveniles were advanced to the next age class:

$$N_{i,a+1,fall} = \begin{cases} N_{i,poult} \\ \sum N_{i,a,fall} \end{cases}$$

We then implemented age- and sex-specific fall harvest. For all harvest regulations, we estimated fall harvest rates of males as approximately 0.09–0.11 throughout New York State (D. R. Diefenbach, unpublished data). Fall female harvest rates varied by harvest regulation. We estimated harvest rates from the results of a 4-year study of female survival in Pennsylvania (D. R. Diefenbach, unpublished data; see below), and we adjusted those rates for changes in bag limits using fall harvest data from New York (1997–2012).

A 4-year study of female turkey survival in Pennsylvania estimated harvest rates of females fitted with reward leg bands or radio-transmitters (Buderman et al. 2014) for 2 years in 2 different management units, with either a 2-week or 3-week fall turkey season. Season lengths in each management unit switched for the last 2 years of the study. The range of harvest rates over the 4 years (for each of the 2-week and 3-week season lengths) became the status quo range of harvest rates in the original 2-week, 1-bird and 3-week, 1-bird fall season zones of New York. We used the difference in harvest rates observed upon changing the season length by 1 week to extrapolate the change in harvest rate ranges for each harvest regulation (Table 1). The results of the study in Pennsylvania closely mirrored the differences in female harvest rates observed in portions of Virginia and West Virginia with differing season lengths (~50% difference in harvest rate between 4-week and 8-week seasons; Pack et al. 1999). Preliminary harvest rates from an on-going study of female survival in New York fell within the range of harvest rates observed in Pennsylvania (M. V. Schiavone, NYSDEC, unpublished data).

We used data from New York's fall turkey harvest to determine the influences of altering bag limits on turkey harvest rates. Approximately 15–25% of the turkeys harvested in the fall in areas with a 2-bird bag limit in New York State was second bird harvest (1997–2012). We increased the harvest rates for TMZs with 1-bird limits by 15% (min. harvest rate) to 25% (max. harvest rate) to approximate the female harvest rate for a season of similar length with a 2-bird limit (Table 1). For example, a harvest rate of 0.05 in a 1-bird limit TMZ would be increased by 0.0075 (0.05×0.15) for a TMZ with a 2-bird limit. For each regulation, we drew age- and sex-specific harvest rates randomly from a uniform distribution of the range of rates predicted under each combination of season length and bag limit. Fall harvest of each individual was the product of a Bernoulli trial in which this randomly drawn harvest rate was the probability of harvest:

$$N_{i,a+1,winter} = N_{s,a+1,fall} - binom\left(N_{i,a+1,fall}, \widehat{h}_{i,a+1,fall}\right)$$

Age- and sex-specific winter mortality followed fall harvest. We estimated baseline winter survival for males in a similar manner to summer survival. We specified the baseline winter survival for females using estimates of monthly survival from females tracked in the 4-year study in Pennsylvania described above (Table 1). We drew age- and sex-specific winter survival rates from a uniform distribution of the range of these estimated rates. To simulate the effects of winter severity on turkey survival, we decreased winter survival for all turkeys by 20% in years in which there were 60 or more days with $\geq$38.1 cm snow depth (Austin and DeGraff 1975). For each year of the simulation, we drew the number of days with $\geq$38.1 cm of snow depth from a normal distribution with the mean and standard deviation calculated from TMZ-specific snow depth data from New York (1988–2013; Table 1). Winter survival of each individual was a product of a Bernoulli trial in which the winter survival rate was the probability of survival. The surviving turkeys became the pre-spring harvest abundance for the next year of the simulation:

$$N_{i,a+1,spring} = binom\left(N_{i,a+1,winter}, \widehat{s}_{i,a+1,winter}\right)$$

For each harvest alternative (i.e., regulation), we simulated the turkey population for 5 years under status quo conditions. We implemented the harvest regulation and simulated the population for another 5 years (yr 6–10), including the status quo option. We calculated pre-fall harvest abundance, fall harvest numbers, and pre-spring harvest abundance as the predicted value at year 10 divided by the predicted value at year 5 (last year of status quo conditions), to estimate a change in each attribute after 5 years of regulation implementation. We simulated 1,000 replicates of the stochastic model per alternative management strategy.

Predicting hunter conflict.—We measured potential conflict with other hunters (objective: minimize conflicts with other hunters) on a constructed utility scale. We used the direct rating method to elicit the expert opinion of NYSDEC biologists, in which we asked experts to rank each regulation and provide relative scores (Goodwin and Wright 2009, Cochrane et al. 2012), and the modified Delphi approach, which allowed experts to discuss their initial results (Kuhnert et al. 2010). For each of the TMZs, we provided information about the current amount of hunter effort and asked the experts to rank each regulation in terms of relative amount of hunter conflict that they expect would occur in that zone. We asked the experts to provide a score (0–100) that reflected how much difference in conflict they would expect among regulations. We provided the anonymous results to all experts for discussion, including their motivations for their own set of scores. Based on this discussion, the experts made changes if they desired. The average of final scores were normalized to a 0–1 utility scale.

Predicting fall observations of turkeys.—The objective to maximize fall observations of turkeys describes the value that hunters placed on the perception that turkeys are abundant on the landscape. However, actual turkey abundance does not correlate perfectly with perception of turkey abundance because of environmental and ecological factors like mast availability (Steffen et al. 2002) and social factors like hunter access to areas of greatest turkey density. To measure perception of turkey abundance, we created a set of TMZ-specific linear regressions that used annual spring turkey harvest numbers (the index of abundance in New York) to predict turkey observations recorded by deer hunters during the archery-only white-tailed deer hunting season (1999–2012) the following fall (an index of fall turkey abundance). With these linear models, we used the expected spring harvest from the population model to predict turkey observations the following fall for each zone.

Tradeoffs

In the tradeoffs step of SDM, tradeoffs are made among the multiple objectives within a decision problem because often no one alternative management action will best achieve all of the objectives. These tradeoffs are made according to stakeholders' values. We elicited tradeoffs in the case of fall turkey harvest in New York via a statewide hunter survey and through a direct rating exercise with NYSDEC biologists and managers.

We implemented a statewide fall turkey hunter survey to obtain information specific to our SDM project (Supplemental Material A, available online in Supporting Information). This survey instrument contained a series of rating and ranking questions that allowed us to calculate weights for the fundamental objectives of hunter satisfaction and the measurable attributes that comprised the fall hunting opportunity objective. We mailed this survey instrument to a stratified random sample of 6,250 turkey hunters throughout New York State (Supplemental Material B, available online in Supporting Information; Siemer et al. 2014).

We used the rank-order centroid method (Edwards and Barron 1994, Goodwin and Wright 2009) and the TMZ-specific results of the ranking portion of the survey (Supplemental Material B; Siemer et al. 2014) to calculate the weights on the hunter satisfaction fundamental objectives. The rank-order centroid method assumes that the differences among weights assigned to the highest-ranked objectives are greater than the differences among the weights assigned to objectives ranked lower (Hajkowicz et al. 2000). We calculated the rank-order centroid weights (w_k) as

$$w_k = \left(\frac{1}{K}\right)\sum_{i=k}^{k}\left(\frac{1}{r_i}\right)$$

where K is the number of objectives and r_i is the rank of the ith objective (Edwards and Barron 1994). We calculated these weights for each survey respondent and averaged the resulting weights across all respondents within each TMZ.

We used the rating portion of the survey to calculate weights on the 2 measurable attributes for the fall hunting opportunity fundamental objective. For each TMZ, we averaged the scores among respondents for the questions related to season length and the scores for the questions related to bag limit, to create a composite score for each attribute. We summed the resulting composite scores and divided the composite score for each attribute by the summed score to determine the attribute weights. We used the weights and normalized measurable attributes (0–1) to calculate a weighted index of hunting opportunity under each harvest regulation (Gregory et al. 2012).

Turkey biologists and managers from NYSDEC provided weights on the overarching fundamental objectives of hunter satisfaction and turkey population growth. Each individual had 10 points to allocate between the 2 objectives. The group then discussed the weights supplied by each individual and agreed upon a consensus weight, which we scaled to 0–1, (0.6 on the turkey population and 0.4 on hunter satisfaction).

We used an additive multi-attribute utility function to calculate the expected utility value $E(U)$ for each regulation (Keeney 1992, Gregory et al. 2012). This utility function was simply a weighted average of the utility scores for each of the individual objectives, weighted according to stakeholder values:

$$\begin{aligned} E(U) = {} & w_{\text{DEC}} \times U_{Population} + w_{\text{DEC}}(w_{\text{Hunters}} \times U_{Conflicts} \\ & + w_{\text{Hunters}} \times I_{HuntingOpportunity} + w_{\text{Hunters}} \times U_{Observations} \\ & + w_{\text{Hunters}} \times U_{HarvestOpportunity} + w_{Hunters} \times U_{HarvestSuccess}) \end{aligned}$$

where w_{DEC} was a weight provided by NYSDEC and w_{Hunters} was a weight calculated from hunter survey data. Each U was a utility score for a measurable attribute, and the I was the weighted index of hunting opportunity. Each of these utility scores must be on the same scale before calculating the expected utility values, so the weights assigned to each objective are interpreted correctly. We normalized the consequences for each objective to a 0 to 1 scale to allow for direct comparisons among objectives. We initially created the utility scale for the hunter conflict objective so that the best performing alternative (i.e., the alternative that best minimized conflict) received a 0. We transposed this utility scale before inclusion in the utility function, so that the best performing alternative for each objective was scored as 1. We determined that the regulation with the greatest expected utility value for each TMZ was the optimal fall turkey harvest regulation for that zone.

We evaluated the sensitivity of the decision in each TMZ to uncertainties in turkey population demographics in 2 ways. We calculated the expected utility value for each TMZ under the mean, 25th, and 75th percentile outputs from the population model. This sensitivity analysis is similar to the process of downside reporting described in Gregory et al. (2012). In addition, in some TMZs, especially the Northern zone, spring harvest was not a good predictor of fall observations, so we evaluated the sensitivity of our decision in each TMZ by calculating the expected utility value with the observations predicted using the upper and lower bounds of the 95% confidence intervals of the slope and intercept of the models.

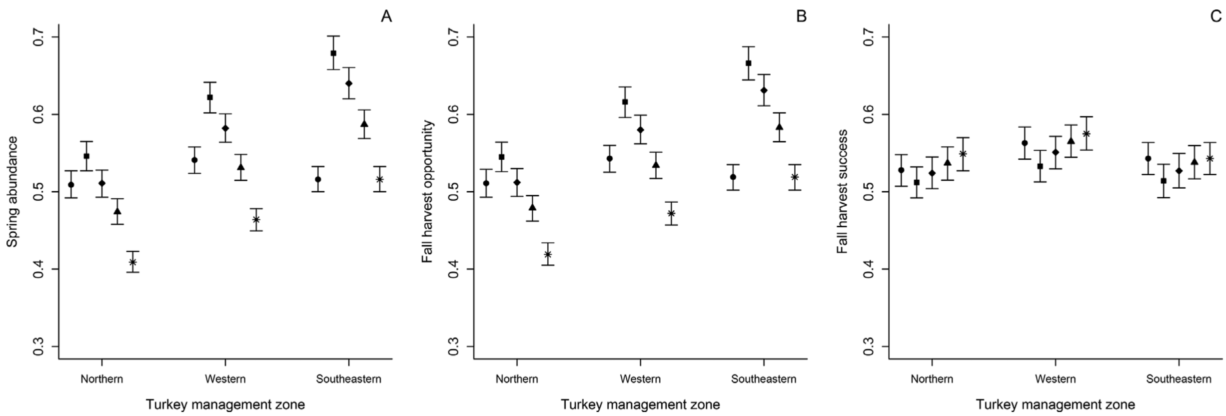

Figure 3. Consequences for the measurable attributes of the fundamental objectives to (A) maximize turkey population size (spring abundance), (B) maximize fall harvest opportunity, and (C) maximize fall harvest success for the fall turkey harvest management in New York, USA, decision problem. Values are the average and 95% confidence intervals of 1,000 simulations of the turkey population model for each turkey management zone, after 5 years under each harvest regulation (simulation year 10), divided by the value at year 5 of the simulation (last year of status quo), providing an estimate of the change in the attribute after 5 years under each regulation. Harvest regulations are status quo (circles), 2-weeks, 1-bird (squares), 3-weeks, 1-bird (diamonds), 4-weeks, 2-birds (triangles), and 7-weeks, 2-birds (stars).

RESULTS

Consequences

Our population model was designed to predict continued declines in abundance in all TMZs after 5 years under status quo (i.e., current) harvest regulations ($\bar{x} = 46–49\%$ decline; 12,454–39,899 fewer birds; Fig. 3, Table S3, available online in Supporting Information). Although abundances in each zone continued to decline under all management regulations, the average decline in abundance after 5 years was least under the 2-week, 1-bird regulation ($\bar{x} = 32–45\%$ decline; 11,460–27,752 fewer birds) and greatest under the 7-week, 2-bird regulation ($\bar{x} = 54–59\%$ decline; 15,067–39,889 fewer birds; Fig. 3, Tables S3 and S4, available online in Supporting Information). Implementing the 2-week, 1-bird regulation, compared to status quo, resulted in 995 (Northern Zone) to 14,006 (Southeastern Zone) more turkeys on the landscape after 5 years (Table S3). The predicted 25th percentile declines in abundance were 66–70% under status quo, 58–68% under the 2-week, 1-bird regulation, and 68–75% under the 7-week, 2-bird regulation (Table S5, available online in Supporting Information). The predicted 75th percentile declines in abundance were 32–35% under status quo, 15–30% under the 2-week, 1-bird regulation, and 35–47% under the 7-week, 2-bird regulation (Table S6, available online in Supporting Information). Likewise, average fall harvest opportunity ($\bar{x} = 46–49\%$ decline) and predicted fall harvest ($\bar{x} = 44–47\%$ decline) continued to decline after 5 years under status quo harvest regulations. Fall harvest opportunity after 5 years was lowest under a 7-week, 2-bird season ($\bar{x} = 48–58\%$ decline) and greatest under the 2-week, 1-bird regulation ($\bar{x} = 33–45\%$ decline). Our population model predicted that fall harvest success would be lowest under the 2-week, 1-bird regulation ($\bar{x} = 47–49\%$ less after 5 years) and greatest under the 7-week, 2-bird regulation ($\bar{x} = 42–46\%$ decline after 5 years; Fig. 3; Tables S4–S6). Similar to harvest opportunity, predicted fall observations increased with decreasing season length (Table S7, available online in Supporting Information).

Expected hunter conflict differed among the TMZs. In the Southeastern and Western zones, the experts predicted that hunter conflict would increase as season length decreased (Fig. 4). In the Northern zone, experts predicted that hunter conflict would be lowest in the 3-week, 1-bird season because the 4- and 7-week regulations would coincide with the hunting season for white-tailed deer. Turkey and white-tailed deer seasons would not overlap in the Southeastern and Western zones.

Tradeoffs

Across all zones, hunters placed the least amount of weight on hunter conflicts (Table 2). In the Northern and Western zones, hunters most valued fall turkey observations, followed closely by fall hunting opportunities. Hunters in the Southeastern zone valued fall hunting opportunities slightly more than turkey observations. Within the fall hunting opportunity objective, hunters statewide placed more value

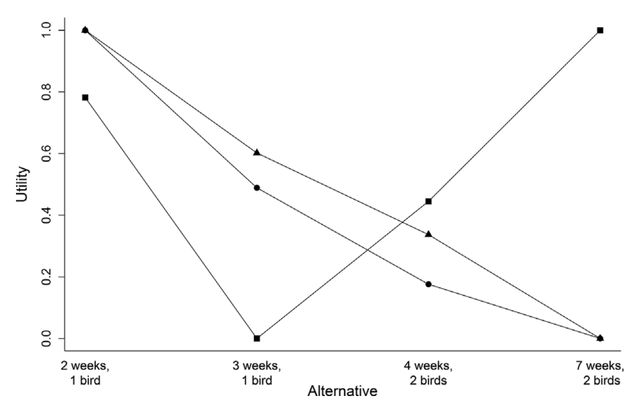

Figure 4. Utility scores for the objective of minimizing conflict with other hunters under each harvest regulation for the Northern (squares), Southeastern (triangles), and Western (circles) turkey management zones in New York, USA. Each regulation is a combination of season length (weeks) and bag limit (no. birds). Regulations with the greatest expected hunter conflict receive a utility score of 1, and regulations with the least expected hunter conflict receive a score of 0.

Table 2. Weights for each of the fundamental objectives related to hunter satisfaction for each turkey management zone in New York, USA, 2013.

	Turkey management zone		
Fundamental objective	Northern	Southeastern	Western
Minimize conflicts with other hunters	0.141	0.137	0.127
Maximize fall hunting opportunity	0.250	0.276	0.223
Maximize fall turkey observations	0.255	0.257	0.278
Maximize fall harvest opportunity	0.193	0.181	0.216
Maximize fall harvest success	0.161	0.149	0.157

on season length (weight = 0.560–0.602) than on bag limit (weight = 0.398–0.440).

In all TMZs, the optimal harvest regulation was the 2-week, 1-bird regulation. Maximizing the turkey population was the most influential objective in the decision model (Fig. 5 and Table 3). The second most influential objective was fall hunting opportunity, which would be best achieved with the 7-week, 2-bird regulation (Fig. 5 and Table 3). The optimal decision (2-week, 1-bird) performed best for 3 (maximize turkey population size, maximize fall harvest opportunity, and maximize fall turkey observations; except in the Northern Zone), of the 6 objectives, and was worst at achieving the other 3 objectives (maximize fall harvest success, minimize conflicts with other hunters, maximize fall hunting opportunity). The optimal decision was robust to the use of the 25th or 75th percentile outputs from the population model (Tables S5 and S6) and the 95% confidence interval predictions of turkey observations in each TMZ (Table S7). In all cases of uncertainty evaluation, the expected utility values did not differ from the values calculated with the average model outputs.

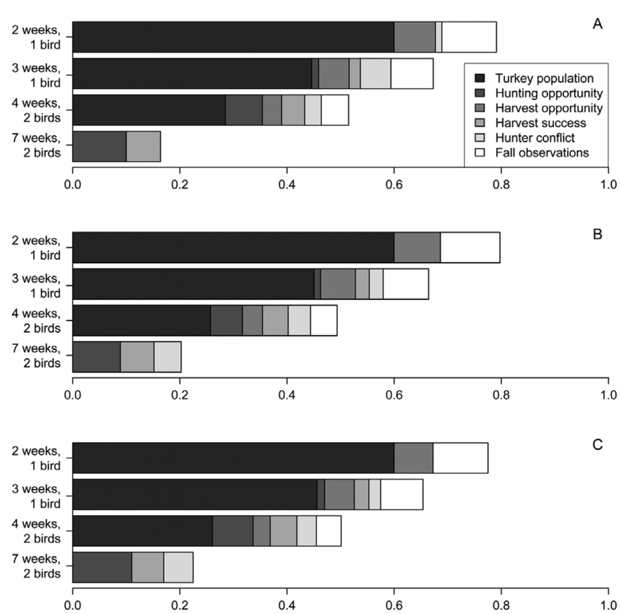

Figure 5. Expected utility value of each regulation (season length, bag limit) of the fall turkey harvest decision problem, broken down by objective, for the (A) Northern, (B) Western, and (C) Southeastern turkey management zones in New York, USA.

DISCUSSION

This case study represents the first use of SDM to develop wild turkey harvest management plans. Structured decision making is very useful for natural resources management (Gregory et al. 2012, Conroy and Peterson 2013), but there are still very few examples of the use of SDM for wildlife management (Robinson et al. 2016, Sells et al. 2016). In our case study, SDM provided a framework to describe the values of stakeholders and predict the consequences of proposed harvest regulations on each of these values. The SDM process maximized the transparency of the decision process by allowing managers to explicitly state what factors were considered when setting harvest regulations and allowed for a formal analysis, thereby reducing the potential for disagreement among stakeholders or with the management agency. The SDM approach we described here can be used to address natural resource management problems, providing a documented process that can be repeated over time, perhaps resulting in a better understanding of the effect of changes in harvest regulations on population dynamics.

The results of our decision analysis for fall turkey harvest in New York highlight one of the most important aspects of the SDM process: the ability to make difficult tradeoffs among multiple competing objectives (Keeney 1992, Gregory et al. 2012). Most often, no one alternative management action will best satisfy all of the objectives. This was the case for fall turkey harvest, in which the optimal regulation (2-week, 1-bird), performed the best for 3 of the 6 objectives and performed worst for the other 3 objectives. Stakeholders placed the greatest value (i.e., objective weights) on the objectives related to turkey availability and population size. Along with the predicted consequences, or outcomes, of the harvest regulation for these objectives, the set of objective weights used in the multi-attribute utility function led to the 2-week, 1-bird season being optimal. Predicting the consequences of each of these harvest regulations on each of the objectives is very important in the process of SDM. However, understanding how the relevant stakeholder groups value these outcomes, in the tradeoffs stage, provides the means for arriving at the final decision (Riley and Gregory 2012).

The optimal regulation (2-week, 1-bird) provided the best balance between turkey population size, fall turkey observations, and fall harvest opportunity among the 4 regulation packages considered. Based on the long-term trend of apparent declines in turkey abundance observed in New York, as indicated by a decline in spring harvest, our model predicted that turkey abundance would continue to decline under all harvest regulations. However, declines in abundance were predicted to be slowest under the 2-week, 1-bird regulation. As compared to the status quo (i.e., current) regulations, the 2-week, 1-bird regulation would slow declines in abundance by 7% in the Northern Zone, 15% in the Western Zone, and 32% in the Southeastern Zone, on average. The differences among zones in declines in abundance are a function of the current

Table 3. Consequence tables for the fall turkey harvest management in New York, USA, decision problem for each turkey management zone. Values for each objective represent the normalized consequences of each set of harvest regulations (alternative; season length, bag limit) on that objective. We used weights in the multi-attribute utility model to calculate the weighted average ($E(U)$ = expected utility value) of each alternative harvest regulation. DEC = New York Department of Environmental Conservation. We normalized all consequences to a 0–1 scale, where 1 is best and 0 is worst. The alternative in each zone with the greatest $E(U)$ is the optimal alternative.

				Alternative					
Zone	Overarching fundamental objective	Hunter satisfaction fundamental objective	Measurable attribute	2 weeks, 1 bird	3 weeks, 1 bird	4 weeks, 2 birds	7 weeks, 2 birds	Weights from hunters	Weights from DEC
Northern zone									
	Max. turkey hunter satisfaction	Min. conflicts with other hunters	Utility scale- change in conflict	0.218	1.000	0.555	0.000	0.141	0.4
		Max. fall hunting opportunity	Weighted index- days and bag limit	0.000	0.127	0.693	1.000	0.250	
		Max. fall turkey sightings or hearings	Predicted bow hunter sightings	1.000	0.769	0.500	0.000	0.255	
		Max. fall harvest opportunity	Number of turkeys harvested relative to status quo	1.000	0.742	0.473	0.000	0.193	
		Max. fall harvest success	Number of turkeys available relative to status quo	0.000	0.331	0.673	1.000	0.161	
	Max. turkey population size		Spring turkey abundance relative to status quo	1.000	0.743	0.476	0.000		0.6
	$E(U)$			0.792	0.672	0.517	0.164		
Southeastern zone									
	Max. turkey hunter satisfaction	Min. conflicts with other hunters	Utility scale- change in conflict	0.000	0.398	0.663	1.000	0.137	0.4
		Max. fall hunting opportunity	Weighted index- days and bag limit	0.000	0.128	0.689	1.000	0.276	
		Max. fall turkey sightings or hearings	Predicted bow hunter sightings	1.000	0.771	0.451	0.000	0.257	
		Max. fall harvest opportunity	Number of turkeys harvested relative to status quo	1.000	0.764	0.439	0.000	0.181	
		Max. fall harvest success	Number of turkeys available relative to status quo	0.000	0.458	0.835	1.000	0.149	
	Max. turkey population size		Spring turkey abundance relative to status quo	1.000	0.760	0.435	0.000		0.6
	$E(U)$			0.663	0.601	0.534	0.337		
Western zone									
	Max. turkey hunter satisfaction	Min. conflicts with other hunters	Utility scale- change in conflict	0.000	0.511	0.824	1.000	0.127	0.4
		Max. fall hunting opportunity	Weighted index- days and bag limit	0.000	0.136	0.670	1.000	0.223	
		Max. fall turkey sightings or hearings	Predicted bow hunter sightings	1.000	0.763	0.447	0.000	0.278	
		Max. fall harvest opportunity	Number of turkeys harvested relative to status quo	1.000	0.754	0.433	0.000	0.216	
		Max. fall harvest success	Number of turkeys available relative to status quo	0.000	0.411	0.764	1.000	0.157	
	Max. turkey population size		Spring turkey abundance relative to status quo	1.000	0.751	0.429	0.000		0.6
	$E(U)$			0.797	0.664	0.494	0.203		

season structure; we observed the greatest response in the Southeastern Zone where the season decreased from 7 weeks to 2 weeks (32% change from status quo), and the smallest response in the Northern Zone where there was a modest 1-week reduction in season length (7% change from status quo). Although not a specific objective of this SDM process, the spring hunting season also would be positively affected by the shorter fall season; the slower decline in abundance would be realized as an increase in the number of turkeys on the landscape prior to the spring season.

Although the optimal regulation (2-week, 1-bird) best achieved the fundamental objective of maximizing the turkey population, we found that manipulation of fall harvest regulations would not completely reverse the apparent declines in turkey abundance. The small expected reduction in female harvest rates, relative to status quo, was not enough to mitigate the negative growth rate that wild turkeys appear to be experiencing in New York. This was especially evident in the Northern zone, with a status quo season length of 3 weeks. Even in the Southeastern zone, which would undergo a 5-week reduction in season length, we still predicted turkey abundance would decline under the optimal harvest regulations. Although a closed fall season was not included in our decision analysis as a viable alternative, the population model predicted that turkey abundance would continue to decline even if the fall season were closed. Reducing the harvest rate of female wild turkeys in the fall still would have a noticeable effect on wild turkey abundance in New York, especially compared to the current fall regulation structure. Fall harvest regulations are one of the fundamental aspects influencing wild turkey abundance over which wildlife managers have some control (Vangilder and Kurzejeski 1995, Healy and Powell 1999). The SDM process helped wildlife managers consider the multiple objectives of stakeholders to allow important tradeoffs to be explicit when setting these fall harvest regulations.

A subjective, or *ad hoc*, approach to decision making for fall turkey harvest regulations likely would have arrived at a similar conclusion as this case study: reducing the season length reduced harvest of female turkeys, which would reduce the rate of decline in abundance. However, we believe that decisions should be evaluated by the quality of the process, not just by the outcome (Jones and Bence 2009). Structured decision making allowed for a formal evaluation of the uncertainty in turkey population demographics that might influence our decision and provided predictions of consequences that are specific to the objectives of stakeholders. Decisions often are mired by uncertainties that could influence the outcomes, particularly for species like turkeys, which undergo large fluctuations in abundance from year to year (Mosby 1967, Healy and Powell 1999). By evaluating the effects of uncertainty in the population model estimates of abundance on the optimal decision, we found that our decision was robust to these large fluctuations in abundance. In addition, implementing a structured process in which we specifically predicted how management actions would affect a set of fundamental objectives showed how stakeholders valued fall turkey hunting and how potential regulations would achieve those values. For example, the results of our study indicated that reducing fall turkey harvest to a 2-week season would not reverse the apparent decline in turkey abundance in New York. The range of harvest rates that we used for the 2-week, 1-bird season in our population simulation model was less than the 10% rule of thumb suggested by Vangilder and Kurzejeski (1995) and the 9% maximum suggested by McGhee et al. (2008), indicating that other aspects of turkey ecology, such as reduced productivity (Casalena et al. 2016), likely are influencing the observed declines in abundance. We also learned that fall turkey hunters in New York placed a greater value on the ability to go afield during the fall and to see turkeys on the landscape than on harvesting a turkey. Based on this information, a new season structure in New York was devised in which the fall seasons in the 3 TMZs do not overlap. With this structure, hunters can still hunt for turkeys for a maximum of 6 weeks in the fall.

The SDM process in our case study for fall turkey harvest management provided valuable information to the state wildlife agency about ecological and social aspects of fall turkey hunting. In addition to determining that fall harvest regulation changes can lessen, but not eliminate, the decline in turkey abundance, we learned about hunters' preferences for a satisfying fall turkey hunting experience. The results of the SDM process provided information about a set of fall harvest regulations that incorporated concerns about declines in turkey abundance throughout the state and the values of fall turkey hunters in New York.

MANAGEMENT IMPLICATIONS

We were able to evaluate how key uncertainties about wild turkey demographics in New York would affect our decision when some objectives were competing and could not be maximized (e.g., maximizing the turkey population and maximizing fall hunting opportunity). The tradeoffs step explicitly acknowledged that certain objectives were valued more than others. Structured decision making provided a transparent, robust, and repeatable process for making decisions about wild turkey hunting regulations.

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Original Article

Using Structured Decision Making to Manage Disease Risk for Montana Wildlife

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ABSTRACT We used structured decision-making to develop a 2-part framework to assist managers in the proactive management of disease outbreaks in Montana, USA. The first part of the framework is a model to estimate the probability of disease outbreak given field observations available to managers. The second part of the framework is decision analysis that evaluates likely outcomes of management alternatives based on the estimated probability of disease outbreak, and applies managers' values for different objectives to indicate a preferred management strategy. We used pneumonia in bighorn sheep (*Ovis canadensis*) as a case study for our approach, applying it to 2 populations in Montana that differed in their likelihood of a pneumonia outbreak. The framework provided credible predictions of both probability of disease outbreaks, as well as biological and monetary consequences of management actions. The structured decision-making approach to this problem was valuable for defining the challenges of disease management in a decentralized agency where decisions are generally made at the local level in cooperation with stakeholders. Our approach provides local managers with the ability to tailor management planning for disease outbreaks to local conditions. Further work is needed to refine our disease risk models and decision analysis, including robust prediction of disease outbreaks and improved assessment of management alternatives.

KEY WORDS bighorn sheep, disease, Montana, *Ovis canadensis*, proactive management, structured decision-making.

Infectious diseases in wildlife are increasing, posing significant threats to the health of wildlife, domestic animals, and human populations and conservation of biodiversity (Daszak et al. 2000). Some of these diseases can result in massive die-offs of wildlife (Young 1994) or in significant commercial losses to livestock operations (e.g., brucellosis; Corbel 1997). Wildlife managers are generally poorly prepared to manage disease outbreaks proactively, relying instead on reactive "crisis management" (Woodroffe 1998). Deem et al. (2001) recommended that disease management for wildlife comprise health surveys, long-term monitoring, and interdisciplinary research, but did not specify how information obtained through such a program could be used to make management decisions. Decker et al. (2006) provided a model for making proactive decisions on wildlife disease management based on public and professional perceptions but did not link the model directly to a process for monitoring or predicting disease outbreaks. Biologists have used decision analysis tools to link estimated probability of disease outbreaks explicitly to decisions for managing endangered species (e.g., Maguire et al. 1987), but to our knowledge this methodology has not been applied to managing disease or its consequences in state-managed wildlife populations.

The purpose of this paper is to present a preliminary, structured decision-making framework (Keeney 2007, Gregory et al. 2012) developed for Montana Fish, Wildlife, and Parks (USA) for discerning the trade-offs of managing disease outbreaks proactively or reactively. The approach comprises 1) estimating the likelihood of a disease outbreak based on information available to managers, and 2) estimating the outcomes of management alternatives, given estimated probabilities of disease outbreak. Structured deci-

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sion-making is a transparent, stepwise process for making complex decisions that includes 1) identifying the problem to be solved, 2) determining fundamental objectives that will be used to evaluate how management actions address the problem, 3) defining alternative management actions, 4) estimating consequences for each management action based on fundamental objectives, and 5) identifying the management alternative that provides the best outcome or combination of consequences (Hammond et al. 1999). Below, we present the results of each step of the structured decision-making process.

PROBLEM STATEMENT

Montana Fish, Wildlife, and Parks has direct experience with wildlife disease events that have affected wildlife conservation and public enjoyment of wildlife resources. For the most part, Montana Fish, Wildlife, and Parks has only reacted to these major disease events and currently has no tools for determining whether taking actions to proactively prevent similar events will produce more desirable results. Future wildlife disease issues in Montana are unavoidable. Montana Fish, Wildlife, and Parks wildlife managers and biologists need risk assessment and decision analysis tools to help prioritize and allocate resources to identify and manage the risk of major disease events. These tools need flexibility in their implementation so that decisions about wildlife management and conservation remain local and community-based.

We structured our decision analysis to reflect the agency structure, the fact that wildlife diseases affect populations of particular species in particular areas, and that 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. In practice, 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 in Montana, but can be generalized into statewide categories of aggressive proactive actions, moderate proactive actions, and reactive actions (i.e., 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 in Montana. A set of models to predict the consequences of management actions on specific wildlife species and health issues, however, can be developed to assist in making those local and regional predictions. Employing these models across Montana using the common framework presented here will facilitate a consistent approach to the way in which local wildlife health management decisions are made. In addition to site-specific consequence predictions, value weights for objectives, trade-offs, and risk tolerance are likely to be specific to each regional wildlife biologist or program manager with responsibility for a particular population of wildlife.

FUNDAMENTAL OBJECTIVES

We identified a set of nested objectives and sub-objectives that are fundamental for a general, proactive wildlife health program in Montana:

1. Maximize wildlife population health, which includes 2 sub-objectives: maximize the probability of population persistence and minimize the probability of a disease outbreak occurring that leads to a major die-off of a wildlife population.
2. Minimize risks posed by wildlife, which includes sub-objectives to minimize risk of disease transmission to livestock and to people.
3. Minimize costs, including sub-objectives to minimize operating costs, personnel costs, and other costs associated with responding to crises.
4. Maximize public satisfaction, which includes sub-objectives to maximize both non-consumptive and hunting opportunities.

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.

To illustrate the decision structure and how the overarching Montana wildlife health program might be applied, we used pneumonia outbreaks among bighorn sheep (*Ovis canadensis*) populations as a case study for working through our decision analysis. Outbreaks of pneumonia in bighorn sheep are commonly tied to contact with domestic sheep and goats and can result in catastrophic die-offs (Foreyt and Jessup 1982, Foreyt 1989, Cassirer and Sinclair 2007, Wehausen et al. 2011). Recently, pneumonia has resulted in large die-offs within populations of bighorn sheep across the western United States, at times necessitating extensive culling efforts in an attempt to control spread of the disease. These die-offs have led to the loss of individual populations and, in some instances, meta-populations (Edwards et al. 2010). Our decision analysis begins to fulfill the management need for establishing a systematic health-monitoring and disease management program identified in the Montana Bighorn Sheep Conservation Strategy (MFWP 2009). For application to management of pneumonia outbreaks in bighorn sheep, we narrowed the objectives to reflect the management context unique to bighorn sheep:

1. Maximize the probability of herd persistence, which we propose to measure by determining whether populations are within objectives or not, as defined by the Montana Bighorn Sheep Conservation Strategy (MFWP 2009). The persistence of populations depends on social tolerance as much as biological carrying capacity and stochastic persistence risks associated with small populations; Montana Fish, Wildlife, and Parks has already established population objectives that consider these factors.

2. Minimize costs, including operational costs, personnel costs, and crisis response costs. We will measure this objective using projected 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.

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. 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, alternatives focus on the relative effort invested in maintaining physical separation of bighorn sheep and domestic sheep and goats. Possible actions managers and biologists could take to manage a major disease event fall within 3 categories:

1. *Reactive management actions*. This involves no attempt to proactively limit interactions between wild and domestic sheep and goats. Population declines lead to populations failing to meet defined objectives, allocation of staff time and resources to cull (if appropriate) sick bighorn sheep, collecting and processing biological samples, sample analysis fees, increased monitoring to detect recovery of collapsed populations, as well as the loss of viewing and hunting opportunities.
2. *Moderate proactive management actions*. These actions will be relatively low-cost and socially acceptable, specific to local circumstances, and the situation as determined by regional wildlife managers and biologists. These may include communicating with landowners or livestock producers to minimize contact between bighorn sheep and domestic sheep or goats, or removing bighorn sheep that commingle with domestics.
3. *Aggressive proactive management actions*. These actions will be more expensive, potentially less socially acceptable, and, again, specific to local circumstances. Actions may include fencing domestic sheep herds to limit interactions between bighorn sheep and domestic sheep or goats, or increasing male bighorn sheep harvest in order to effect a decline in the adult male:adult female ratio (thereby preventing the spread of disease by wide-ranging males during the rut).

PREDICTING THE LIKELIHOOD OF A MAJOR DISEASE EVENT

Development of predictive models for the risk of wildlife disease events would help wildlife managers in their decision-making processes. Predictive 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 site-specific management options.

To illustrate this, we developed a risk assessment model to predict the probability of a major disease event for a herd of bighorn sheep over a 10-year time horizon. We defined a major disease event as one with ≥50% mortality in any 1 year. The model was simple (Table 1): the probability (Pr) of a major disease event in any 1 year was a function of Pr(exposure), E; Pr(susceptibility), S; and Pr(risk of spread), R.

For our case study, we assumed E 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 cue reflected a subjective, relative weighting of importance as decided upon by the experience and expertise of our team. We defined E as the sum of the assigned values for each cue, divided by the maximum possible value for the sum (Table 1).

We assumed S could be predicted by the unweighted average of several cues, including assessments of clinical condition, habitat condition, and low recruitment of lambs (lamb mortality is high during and following pneumonia outbreaks). We estimated S as the average value (range = 0–3) assigned to each of 6 potential indicators, divided by 3, the maximum possible value for the average. Indicators for which no information was available did not contribute to the average (Table 1).

We assumed R could be predicted by the density and distribution of bighorn herds, and the observed ratio of adult males to adult females (males range much more widely than females and are thought to be important vectors for spread of disease among herds). We defined R as the sum of the assigned values for each, divided by 9, the maximum possible value for the sum (Table 1).

We defined the Pr(major disease event in any 1 yr) as the product of E, S, and R. The probability of *no* major disease event in t years is $1 - \text{Pr(major disease event in any 1 yr)}^t$. Over a time horizon of 10 years, the probability of observing at least one major event was $1–[1 - \text{Pr(major disease event in any 1 yr)}]^{10}$ (Mood et al. 1974).

Our model was constructed in a spreadsheet so that regional wildlife biologists and managers could use it to 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

Table 1. Disease risk model for estimating the probability of a major disease outbreak (i.e., ≥50% mortality in a population) for bighorn sheep (*Ovis canadensis*) in Montana, USA, based on estimated exposure, E, susceptibility, S, and risk of spread, R. Annual risk of a major disease outbreak $= E \times S \times R$.

Metric	Score[a]
Risk of exposure, E	If $E2 = 8$, then $E = 1$, else $E = \frac{\sum(E1, E2, E3)}{\sum(E1^{max}, E2^{max}, E3^{max})}$
Contact with domestic sheep and goats, $E1$	
Highly unlikely	0
Within range of forays	2
Within ≤7 miles	4
Within home range	6
Contact with infected bighorn sheep, $E2$	
Highly unlikely	0
Within range of forays	2
Within adjacent herd	4
Within home range	8
Current presence of pathogens, $E3$	
Absent or unknown	0
Present in the past	1.5
Known to be present	3
Susceptibility, S	$S = \frac{\sum(S1, S2, S3, S4, S5, S6)/6}{3}$
Body condition, $S1$	Low (0), medium (1.5), high (3)
Parasite load, $S2$	Low (0), medium (1.5), high (3)
Blood parameters, $S3$	Low (0), medium (1.5), high (3)
Range measures, $S4$	Low (0), medium (1.5), high (3)
Mineral levels, $S5$	Low (0), medium (1.5), high (3)
Lamb:F ratio, $S6$	Poor (3), low (2), medium (1), high (0)
Risk of spread, R	$R = \frac{\sum(R1, R2, R3)}{\sum(R1^{max}, R2^{max}, R3^{max})}$
Herd density, $R1$	
Within Montana Fish, Wildlife, and Parks objectives	0
Slightly over Montana Fish, Wildlife, and Parks objectives	1.5
Well over Montana Fish, Wildlife, and Parks objectives	3
Herd distribution, $R2$	
Normal-sized herds	0
Large herds, small natural areas	1.5
Large herds, small artificial areas	3
M:F ratio, $R3$	Low (0), medium (1.5), high (3)

[a] Scores assigned to sub-metrics are based on subjective evaluation of relative contribution to overall risk of disease outbreak.

uniform tool for managers to assess and compare alternative, local management actions and to engage stakeholders in the decision process.

To evaluate the usefulness of this model in informing management decisions, we parameterized the model for the Missouri Breaks bighorn sheep herd in eastern Montana and the Petty Creek bighorn sheep herd in western Montana (Fig. 1). We chose these herds because the herd managers were present on our team, and because they represented different disease contexts in different parts of Montana. We parameterized the model for the 3 management alternatives (reactive 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 regarding clinical and habitat conditions. We elicited values for calculating E, S, and R under the assumption they equated with relative probabilities.

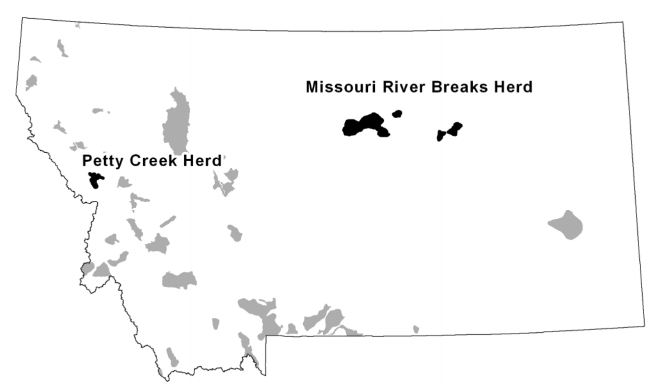

Figure 1. Locations of bighorn sheep (*Ovis canadensis*) herds in Montana, USA. Darkened polygons represent the Petty Creek herd in western Montana, and the Missouri Breaks herd in central Montana. The 2 herds experience 2 different environments affecting likelihood of major disease outbreak. The Petty 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.

DECISION ANALYSIS

For both the Missouri Breaks and Petty Creeks herds, we constructed a decision tree (Behn and Vaupel 1982; Table 2) to estimate the consequences of the 3 management alter-

Table 2. Example of a decision table with estimated consequences for 3 alternative strategies for managing disease outbreak in bighorn sheep (*Ovis canadensis*) within the next 10 years proactively, illustrated for a population of bighorn sheep living in Petty Creek, Montana, USA. The top row contains fundamental objectives, the second row contains whether objectives were to be minimized or maximized, the third row contains measurable attributes for each objective, and the fourth row the scale on which they are measured. The remaining 3 rows contain the estimated consequences under each objective in the event a major disease outbreak does and does not occur, and the "expected" or the probability-weighted average outcome, under each of the 3 management alternatives (Behn and Vaupel 1982). Probabilities of disease or no disease are estimated from the disease risk model in Table 1.

Management alternative	Fundamental objective:	Probability of persistence	Operating costs	Personnel costs	Crisis response	Viewing opportunity	Hunting opportunity
	Goal:	Maximize	Minimize	Minimize	Minimize	Maximize	Maximize
	Attribute:	Meet population objective?	US$ cost/ 10 yr	Person-days/ 10 yr	US$ cost/ 10 yr	Meet population objective?	No. licenses sold/10 yr
	Scale:	1 = yes, 0 = no	US$K/10 yr	Days	US$K/10 yr	1 = yes, 0 = no	No./10 yr
Aggressive, proactive	Pr(disease) = 0	0	105	220	80	0	100
	Pr(no disease) = 1.0	1.0	105	220	0	1.00	200
	Expected outcome[a]	0.9	105	220	8	0.90	190
Moderate, proactive	Pr(disease) = 0.2	0	100	170	80	0	75
	Pr(no disease) = 0.8	1.0	100	170	0	1.00	150
	Expected outcome	0.8	100	170	16	0.80	135
Reactive	Pr(disease) = 0.6	0	0	0	80	0	75
	Pr(no disease) = 0.4	1.0	0	0	0	1.00	150
	Expected outcome	0.4	0	0	48	0.40	105

[a] Expected outcome = [consequence of disease × Pr(disease)] + [consequence of no disease × Pr(no disease)].

natives. Probabilities describing the chance of 2 possible states—the occurrence or non-occurrence of a major disease event within 10 years—were used to estimate "expected consequences," or the average of the consequences with and without disease weighted by the probability of whether a major disease event would occur under each management alternative (Table 2). Then we used these expected or probability-weighted outcomes to assess the managers' preferences for balancing between their objectives, using the Simple Multi-Attribute Rating Technique (Edwards 1971, Goodwin and Wright 2004). For both herds, we normalized the expected consequences across the range in our alternatives for each objective and weighted them according to the value judgments of these local bighorn sheep herd managers, elicited using swing weighting (von Winterfeldt and Edwards 1986). We then aggregated judgments using simple weighted summation to characterize the overall value of each alternative (Table 3).

Our analyses for the Petty Creek and Missouri Breaks herds provided a good test of the ability of this decision

Table 3. Example of a Simple Multi-Attribute Rating Technique decision analysis evaluating 3 management alternative to proactively managing disease outbreak in bighorn sheep (*Ovis canadensis*; no proactive management, moderate proactive management, and aggressive proactive management), illustrated for a population of bighorn sheep living in Petty Creek, Montana, USA. 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, estimated by swing weighting based upon the range of expected outcomes for each objective (Table 2). Weights were determined subjectively by decision-makers and sum to 1. The final 9 rows contain the expected outcomes, their normalized score, and their weighted score for each of the fundamental objectives under each of the 3 management strategies and in the last column the sum of normalized, weighted scores, indicating relative support of the decision analysis for each management alternative (Goodwin and Wright 2004).

Management alternative	Fundamental objective:	Probability of persistence	Operating costs	Personnel costs	Crisis response	Viewing opportunity	Hunting opportunity	Summed normalized, weighted scores
	Goal:	Maximize	Minimize	Minimize	Minimize	Maximize	Maximize	
	Measurable attributes:	Meets population objective?	US$ cost/ 10 yr	Person-days/ 10 yr	US$ cost/ 10 yr	Meets population objective?	No. licenses sold/10 yr	
	Weight:	0.21	0.15	0.14	0.19	0.15	0.18	
Aggressive, proactive	Expected outcome[a]	0.9	105	220	8	0.9	190	
	Normalized score	1.00	0.00	0.00	1.00	1.00	1.00	
	Weighted normalized score	0.21	0.00	0.00	0.19	0.15	0.18	0.72
Moderate, proactive	Expected outcome	0.8	100	170	16	0.8	135	
	Normalized score	0.80	0.05	0.23	0.80	0.80	0.35	
	Weighted normalized score	0.17	0.01	0.03	0.15	0.12	0.06	0.53
Reactive	Expected outcome	0.4	0	0	48	0.4	105	
	Normalized score	0.00	1.00	1.00	0.00	0.00	0.00	
	Weighted normalized score	0.00	0.15	0.14	0.00	0.00	0.00	0.28

[a] From Table 2.

analysis system to assist managers in making decisions. The 2 herds experience very different environments affecting the likelihood of disease outbreaks. The Petty Creek herd is at a high-risk of exposure 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 disease risk model and decision analysis tools 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.

Given input by species experts and managers and assuming current management practices continue, the risk analysis model predicted the probability of a major disease event within the next 10 years to be 0.56 for the Petty Creek herd and 0.18 for the Missouri Breaks herd. 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 (Table 3; Fig. 2). By contrast, the analysis for the Missouri Breaks herd showed strong support for either aggressive or moderate proactive management, with little support for reactive management (Fig. 2).

DISCUSSION

To facilitate the development of a wildlife health program for the state of Montana, we used a structured decision-making approach to define the problem, establish fundamental objectives, identify alternative management actions, and define metrics of success. During this process we developed a model to estimate the probability of a disease outbreak and linked this model with decision analysis that allows managers to proactively evaluate likely effects of alternative actions on both disease risks and fundamental management objectives. Carefully structuring the analysis led to substantial progress that would not have been possible otherwise. The major value of this approach came from the focused thinking and debate on the problem statement, the objectives of the program, 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 centralized decision-making authority. This clarity would not have been possible without carefully delineating the various elements of the actual decision.

We designed a framework that assists regional managers in reaching local decisions reflecting statewide wildlife conservation objectives. The framework we developed addresses 2 of the most challenging components of decision-making in wildlife conservation and disease management in particular: the inherently probabilistic nature of disease events and effects, and the inherent tensions among Montana Fish, Wildlife, and Parks's fundamental objectives. To this end, we employed a combination of modeling and decision analysis tools, including a predictive risk model, a decision tree, and Simple Multi-Attribute Rating Technique trade-off analysis and management alternatives scoring.

Although we have explored the value of the more technical aspects of this decision framework (e.g., models used to predict the consequences of alternative management actions relative to meeting objectives), their full potential has not yet been fully realized. To use the model we developed for predicting the risk of major disease events in bighorn sheep herds to inform decisions about bighorn sheep management, more focused work on model development and reliability is required. This technical work is appropriate 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 help managers make decisions that are better for having used the models than they would have been otherwise. Work to increase the accuracy of predictive models is warranted if it improves the decision analysis, affecting not only the consequence predictions but the indicated choice among management options and confidence those actions will achieve management's fundamental objectives.

In our bighorn sheep model, for example, the measurable attributes relative to the population objectives are likely oversimplified. 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 fall marginally outside objective bounds are thus assigned zero value, which may prove unrealistically simple for assessing trade-offs that wildlife managers need to make. In future application, the attribute may

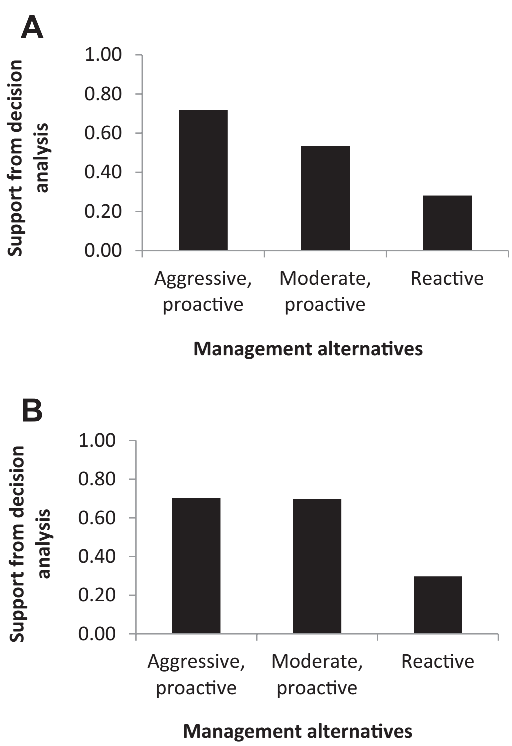

Figure 2. Results of decision analyses for disease management in the Petty Creek (A) and Missouri Breaks (B) herds of bighorn sheep (*Ovis canadensis*) in Montana, USA. Graphs illustrate relative support for the 3 management alternatives between the 2 herds.

be constructed such that all population sizes within objective bounds receive the highest possible value, while population sizes outside of the objective range are scored lower the further from the objective bounds they are (*sensu* Keeney 2007). Similarly, we used population objectives as measurable attributes for 2 fundamental objectives; future application should identify a distinct and more focused attribute for public satisfaction instead of duplicating the population persistence attribute. This should allow managers the flexibility needed to make trade-offs in management decisions when necessary.

Uncertainty within the risk analysis model also needs to be addressed. The illustrative model we developed for bighorn sheep is a simple linear additive model built on expert judgment, which although generally robust to uncertainty (Dawes 1979, Dana and Dawes 2004), could be improved substantially. 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 do the following:

1. Coordinate with other experts in Montana to ensure all of the key factors influencing probabilities of pneumonia outbreaks are captured in the modeling framework, and factors used to predict probabilities of pneumonia outbreaks are measured and weighted relative to each other in an epidemiologically credible manner.
2. Use statistical model(s) to predict disease outbreaks using the available historical data, in order to 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 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. The sensitivity analysis needs to reveal the extent to which these critical assumptions affect overall predictions of the probability of disease outbreaks and resulting choice of preferred management actions. The sensitivity analysis can inform how much effort is warranted toward improving the models, including identifying more nuanced and accurate relationships between risk and exposure than the simple linear relationship assumed in the case study.
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 these tools are used to inform decisions.

Ultimately, the Montana wildlife health program must be structured as the agency is structured. To be effective and sustainable it should be fully integrated into the broader wildlife conservation program via a focus on unifying wildlife conservation objectives. The overall mission 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. This context is imperative because the mission of state and federal wildlife agencies is more focused on fundamental wildlife conservation objectives than on elimination or limitation of wildlife disease. By using this framework, undesirable consequences of wildlife disease for effective wildlife conservation need to be identified before resources are expended to manage disease transmission or monitor the disease. Undesirable consequences of wildlife disease are not necessarily universal, for example parasites and diseases can have fundamental roles in ecosystem function (Eviner and Likens 2008), and in many cases the ecological consequences of diseases are virtually unknown (Deem et al. 2008). In addition, some actions designed to limit disease spread will require trade-offs for objectives valued for other aspects of wildlife conservation (e.g., reductions in wildlife population sizes). Without placing a wildlife health program in a decision analysis context such as Simple Multi-Attribute Rating Technique, such trade-offs could not be made explicit. Objectives may 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.

Both the disease risk model and decision analysis tools 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 expanded to encompass diseases such as brucellosis, chronic wasting disease, etc., and other wildlife species that are affected by health issues. Whereas 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.

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Research Article

Addressing Wild Turkey Population Declines Using Structured Decision Making

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ABSTRACT We present a case study from New York, USA, of the use of structured decision making (SDM) to identify fall turkey harvest regulations that best meet stakeholder objectives, in light of recent apparent declines in abundance of wild turkeys in the northeastern United States. We used the SDM framework to incorporate the multiple objectives associated with turkey hunting, stakeholder desires, and region-specific ecological and environmental factors that could influence fall harvest. We identified a set of 4 fall harvest regulations, composed of different season lengths and bag limits, and evaluated their relative achievement of the objectives. We used a stochastic turkey population model, statistical modeling, and expert elicitation to evaluate the consequences of each harvest regulation on each of the objectives. We conducted a statewide mail survey of fall turkey hunters in New York to gather the necessary information to evaluate tradeoffs among multiple objectives associated with hunter satisfaction. The optimal fall harvest regulation was a 2-week season and allowed for the harvest of 1 bird/hunter. This regulation was the most conservative of those evaluated, reflecting the concerns about recent declines in turkey abundance among agency wildlife biologists and the hunting public. Depending on the region of the state, the 2-week, 1-bird regulation was predicted to result in 7–32% more turkeys on the landscape after 5 years. The SDM process provided a transparent framework for setting fall turkey harvest regulations and reduced potential stakeholder conflict by explicitly taking the multiple objectives of different stakeholder groups into account.

KEY WORDS decision analysis, harvest regulations, management, *Meleagris gallapavo*, New York, population model, structured decision making, wild turkey.

In the northeastern United States, spring wild turkey (*Meleagris gallapavo*) harvest steadily increased in the 1990s but more recently either has declined (Mid-Atlantic states) or the rate of increase has slowed (New England states; Casalena et al. 2016). The concurrent observed declines in reproductive success in the northeastern United States indicate that turkey abundance has decreased from a peak that was reached during restoration (Casalena et al. 2016). The apparent decline in turkey abundance potentially could be slowed or reversed through implementation of management actions. For example, habitat management activities could be designed to increase recruitment and adult female survival in the breeding season (Jimenez and Conover 2001, Casalena et al. 2007, Fuller et al. 2013), and changes in fall harvest regulations could reduce harvest of females and offset the decline in abundance. Spring harvest is the greatest source of mortality for male turkeys (Godwin et al. 1991, Paisley et al. 1996, Wright and Vangilder 2005, Diefenbach et al. 2012), but the fall either-sex turkey harvest has a greater effect on population dynamics because harvest of females in the fall is greater than in the spring (Vangilder and Kurzejeski 1995, Alpizar-Jara et al. 2001, McGhee et al. 2008, Stevens et al. 2016). Re-evaluating fall turkey harvest regulations is an appropriate first step to take to mitigate the apparent decline in turkey abundance because of the

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potential ability of reductions in female harvest to offset the apparent declines in abundance (Vangilder and Kurzejeski 1995, Alpizar-Jara et al. 2001, McGhee et al. 2008, Stevens et al. 2016), and because these regulations can be changed with relative ease.

Despite the potential for mitigating apparent declines in turkey abundance, fall harvest regulations involve many social and ecological considerations that increase the complexity of the decision. Complex tradeoffs to consider include turkey population dynamics and the associated uncertainties in turkey demographic rates, stakeholder desires (e.g., hunting opportunity), and management zone-specific environmental factors that influence fall turkey harvest and population demographics (e.g., land cover and land use [Porter and Gefell 1996], spring weather [Porter and Gefell 1996], and winter severity [Porter et al. 1980, Vander Haegen et al. 1989]). Explicit incorporation of stakeholder values as elicited directly from stakeholders, in addition to ecological values, would allow for consideration of diverse objectives inherent in harvest management decisions. Any potential harvest regulations could be evaluated in terms of the entire set of objectives, and a formal evaluation of the tradeoffs subsequently can be made among those objectives.

Structured decision making (SDM) provides a framework that can incorporate the multiple objectives and tradeoffs associated with management decisions, such as those inherent to turkey management. The goal of the SDM process is to aid authorities responsible for management action by providing insight and information about the decision, including the multiple objectives of different stakeholder groups, key uncertainties, and important tradeoffs (Clemen 1996, Gregory et al. 2012). The SDM process guides decision maker(s) through the steps of defining the problem, determining all relevant objectives, identifying a set of management actions, predicting the effect of each management alternative on the objectives, and evaluating the tradeoffs that must be made among objectives (Hammond et al. 1999, Gregory et al. 2012). The SDM process separates values, in the objectives and tradeoffs stages, from science, in the consequences stage. This problem decomposition results in a management decision that is values-driven (i.e., focused on stakeholders' values; Keeney 1992), explicitly incorporates uncertainty (Runge 2011, Moore and Runge 2012), and transparent, in the sense that it improves communication about the manner in which the decision was made (Gregory and Keeney 2002). Because stakeholders can see how their concerns are incorporated into the decision, and how well each management action achieves their objectives, the optimal decision often garners more support from stakeholder groups than decisions made with a less transparent process (Decker et al. 2012, Riley and Gregory 2012) or those that lack a formal evaluation of the different alternatives.

We use New York, USA, as a case study to demonstrate how an SDM framework can identify management zone-specific fall turkey harvest regulations that would best achieve multiple stakeholder objectives, while taking into account key uncertainties and tradeoffs. The ecological and social aspects of this management decision required the type of problem decomposition inherent in SDM. Tradeoffs included those between objectives related to hunter satisfaction and reducing the declines in turkey abundance. Multiple dimensions of experience affect hunters' perceptions of a satisfying turkey hunting experience (Hazel et al. 1990, Siemer et al. 1995, Wynveen et al. 2005). Wildlife agencies are challenged to address multiple, sometimes competing, hunter objectives. For example, hunter surveys indicate that seeing and hearing turkeys and having ample opportunities to harvest turkeys contribute to hunting satisfaction for substantial numbers of turkey hunters (Siemer et al. 1995, Wynveen et al. 2005), but seeing or hearing turkeys and expanding opportunities to harvest turkeys are management objectives that could be in conflict (i.e., achieving one of those objectives may compromise ability to achieve the other). Our research addressed wildlife managers' uncertainty regarding what factors contributed to hunter satisfaction with current fall turkey hunting opportunities and about potential causes of a decline in fall turkey hunter effort. We implemented a statewide survey of fall turkey hunters to identify how hunters value these multiple dimensions of satisfaction, determine whether these values differed among regions of the state, and alleviate uncertainties about hunter satisfaction. Additionally, we evaluated uncertainty in the demographic responses of turkeys in 3 newly delineated management units to changes in fall season structure and the effects of ecological factors on turkey survival and harvest. This project required the cooperation of scientists and managers of the state wildlife agency, social scientists and ecologists from academia, and decision analysts and ecologists from the federal government. The ranges of stakeholder values and data necessary to make informed and robust decisions for natural resources management required a multi-disciplinary approach, and SDM effectively used these collaborations. Through the SDM process, we provided a framework for the state agency to take the various considerations into account and make a decision about how best to manage fall turkey harvest.

STUDY AREA

Our study area was the state of New York (74,576 km^2, elevation range 0 to >1,500 m), which is divided into 6 climate regions that experience a range of temperatures and precipitation patterns across the seasons (Thompson 1996, Bowling 2014). New York's landscape includes ecoregions that range from evergreen forests in the Adirondack region, to flat landscapes with many wetlands in the St. Lawrence Plain and Champlain Valley, to agriculturally dominated landscapes in the western part of the state (Bailey 1995, Bowling 2014). We divided our study area into turkey management zones (TMZs), defined based on similarities in turkey demographics and landscape characteristics (Bowling 2014). Each TMZ contained multiple wildlife management units (Fig. 1), the geographic unit of management that the New York State Department of Environmental Conservation (NYSDEC) used to set hunting regulations for multiple wildlife species. We did not evaluate fall harvest regulations

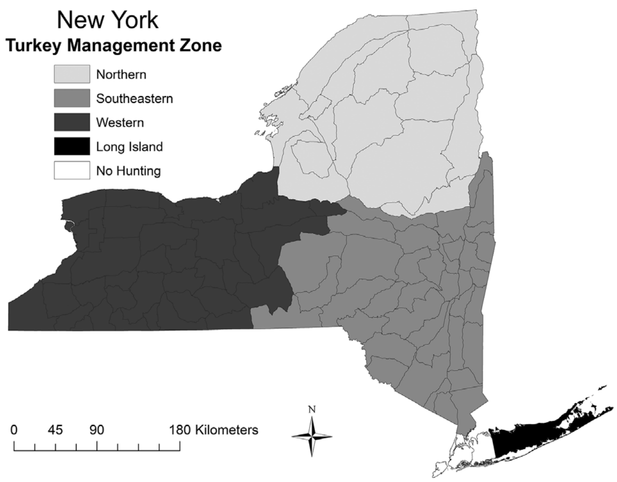

Figure 1. Four turkey management zones in New York, USA. Lines represent wildlife management units for New York.

for the Long Island TMZ (619 km^2), where the current fall season (1 week, 1 bird) was the shortest in the state. Although biological and social data for this region were limited, measures of abundance from surveys and the existing hunting season indicated that turkey densities in Long Island were similar to or greater than portions of upstate New York that have similar or longer hunting seasons. In addition, hunting pressure in Suffolk County was lower than in the rest of the state. Based on the limited data on turkey abundance and hunting participation and effort in Suffolk County, we applied the most conservative outcome from the analysis of the other 3 turkey management zones to the Long Island zone.

METHODS

The management decision was decomposed into the problem, objectives, alternatives, consequences, and tradeoffs (PrOACT; Hammond et al. 1999). The problem statement contained the background to establish the fundamental and means objectives of the decision problem. Fundamental objectives define what the decision makers fundamentally value, whereas means objectives provide a pathway for achieving those fundamental objectives (Keeney 1992). We used these objectives to guide the creation a set of management alternatives for fall turkey harvest regulation. We created a population model to evaluate the effect of each management alternative on turkeys in each TMZ. We used a multi-attribute utility function that included the results of the population model, expert opinion, and stakeholder values, to determine the management strategy that best achieved the multiple objectives.

Problem Statement

The problem statement, which guides the rest of the decision process (Hammond et al. 1999), contained information about the most important factors for the decision about fall turkey hunting season structure in New York, the ultimate decision maker, and spatial and temporal aspects of the problem. The decision maker was the Commissioner of NYSDEC, with agency staff representing the delegated authority for this decision. We developed a working group of NYSDEC biologists and managers, natural resource professionals (NYSDEC, Pennsylvania Game Commission [PGC]), experts in social science (Cornell University), and experts in decision analysis (United States Geological Survey [USGS], Cornell University) and wild turkey management (USGS, PGC, NYSDEC; 10 people in total). The working group expressed concerns related to perceived declines in turkey abundance and uncertainty about hunter attitudes and opinions. Managers also stated that, in light of the concerns about the apparent decline in turkey abundance informally expressed by turkey hunters, a more structured and transparent process for setting regulations that allowed for a formal evaluation of the alternative management regulations was important for stakeholder support of any new regulations. The stated goal for harvest management was to provide a sustainable wild turkey population to provide optimal opportunities for hunters and others to enjoy the wild turkey resource now and in the future, while being sensitive to potential negative impacts of fall turkey hunting on turkey population growth. The problem statement recognized that simultaneously maximizing abundance of turkeys and hunting opportunity was not possible (hence, the use of the word optimal) and provided the relevant information to develop a set of fundamental objectives for the decision analysis.

Objectives

We developed the fundamental objectives in a hierarchy, reflecting the values of the state wildlife management agency, the hunting public, and others who value turkeys (e.g., bird watchers or those who enjoy seeing turkeys). Two overarching fundamental objectives described the values of the stakeholders, as determined by the working group: maximize the turkey population and maximize hunter satisfaction. Given the focus on fall harvest regulation for managing turkey abundance, the turkey population would be maximized through the means objective of minimizing female mortality due to fall hunting. We measured the turkey population objective as the predicted number of turkeys on the landscape in a given TMZ just prior to spring harvest, relative to the number under current regulations (status quo). Status quo regulations in New York consisted of a season length from 1 to 6 weeks and a bag limit of 1 or 2 turkeys, depending on the region of the state.

We created a set of fundamental objectives for hunter satisfaction based on research that described various components of hunter satisfaction (Hendee 1974, Decker et al. 1980, Hammitt et al. 1990, Enck and Decker 1991, Siemer et al. 1995). We used research about hunter satisfaction and the expert opinion of the working group to create the objectives in lieu of working directly with hunting groups. Although hunters were not included in the creation of objectives, we created a hunter survey (see below) to allow hunters to express how they value each of these components of hunter satisfaction. We established 5 objectives and their associated performance measures.

1. Minimize conflicts with other hunters (turkey or other game). Hunter conflict refers to a potential decrease in satisfaction as hunter density on the landscape increases. We measured hunter conflict as a constructed attribute. A constructed attribute is a scale of measure that is created specifically for a decision context (Keeney 1992). In this case, the constructed attribute was a 0–1 utility scale in which 0 = the regulation that produces the least amount of conflict and 1 = the regulation that produces the most amount of conflict, with intermediate values representing intermediate levels of conflict.
2. Maximize fall hunting opportunity. We measured hunting opportunity as the season length and the number of turkeys that each hunter legally was allowed to harvest during the season (bag limit).
3. Maximize fall observations of turkeys. Seeing turkeys can be inhibited by environmental factors, such as high levels of mast that would disperse turkeys across the landscape or cluster turkeys in areas that are not available for hunting (Steffen et al. 2002). Therefore, the perception of the availability of harvestable turkeys can differ from the actual number of turkeys on the landscape. We measured fall observations as the predicted number of turkey observations made by white-tailed deer (*Odocoileus virginianus*) archery hunters (bow hunter sighting index) just prior to the fall hunting season.
4. Maximize fall harvest opportunity. We measured harvest opportunity as the predicted number of turkeys on the landscape, relative to the number available under current regulations, just prior to fall harvest.
5. Maximize fall harvest success. We measured harvest success as the expected number of turkeys harvested, relative to the number harvested under current regulations.

Alternatives

We developed a finite set of regulations, or alternatives, to achieve the stated objectives. Although we could have identified an infinite number of regulations, we wanted a small, discrete set that we expected to differ measurably in their ability to satisfy the various objectives. In addition, the group considered only regulations that would be viable for implementation (e.g., a total closure of the fall season would not be considered or implemented by the state). The working group considered 4 possible regulations that were combinations of season length (2–7 weeks) and bag limit (1–2 birds) thought to best achieve the fundamental objectives. The regulations considered were 2-week season and 1-bird limit, 3-week season and 1-bird limit, 4-week season and 2-bird limit (1 bird/day), and 7-week season and 2-bird limit. The group thought that these 4 regulations could best achieve each of the fundamental objectives or might perform best when tradeoffs were made among these objectives.

Consequences

Consequences predict the relative achievement of each objective by each alternative. We used output from a turkey population simulation model, linear modeling of fall turkey sighting data collected by NYSDEC, and expert opinion to predict the consequences of each alternative on each of the fundamental objectives (maximize turkey population size, maximize fall harvest success, maximize fall harvest opportunity, minimize conflicts with other hunters, maximize fall observations of turkeys).

Population model.—We created a stochastic, stage-based simulation model in R (R Core Team 2014) to predict age- and sex-specific fall harvest success (objective: maximize fall harvest success), age- and sex-specific availability of turkeys for fall harvest (objective: maximize fall harvest opportunity), and change in abundance (objective: maximize turkey population size) under the 4 harvest regulation alternatives. We parameterized the model with data from New York and other studies of turkeys in the northern United States (Table 1). The model simulated the population dynamics of poults (<0.4 yr old) and juvenile (<1.4 yr old) and adult (≥1.4 yr old) males and females on an annual cycle (Fig. 2). The output of this population model provided values for the measurable attributes related to turkey abundance and turkey harvest.

The population model began with a pre-spring-harvest density of turkeys that was drawn from a uniform distribution with a TMZ-specific range (Table 1). We chose the range of densities for each zone such that the predicted number of birds harvested in the spring under status quo regulations was similar to actual spring harvest in each TMZ (1999–2012). We calculated the initial number of turkeys (N_o) on the landscape as the initial density multiplied by the area of the TMZ. We divided N_o into males and females by drawing an adult sex ratio (75 M/100 F) from a normal distribution with mean proportion of males = 0.43 and coefficient of variation (CV) = 10% (Hayden and Wunz 1979). The sex-age structure of the simulated population was based on published age structures from tagging studies of females (WI; Rolley et al. 1998) and males (NY; Diefenbach et al. 2012). We calculated the sex- and age-specific initial abundance (N) based on the proportion (Pr) of each sex (i) and age (a; juvenile or adult):

$$N_{i,a,spring} = N_o \times Pr_{i,a}$$

We first subjected male turkeys to spring harvest. We drew spring harvest rates ($\hat{h}$) randomly each year from a uniform distribution of age-specific rates estimated for each TMZ of New York (Diefenbach et al. 2012; Table 1). Harvest of each individual was the product of a Bernoulli trial in which the age-specific harvest rate was the probability of mortality:

$$N_{male,a,summer} = N_{male,a,spring} - binom\left(N_{male,a,spring}, \hat{h}_{male,a,spring}\right)$$

Previous research estimated harvest of bearded females to be <1% in New York (D. R. Diefenbach, U.S. Geological Survey, unpublished data), similar to reported rates in Missouri (Vangilder and Kurzejeski 1995) and Virginia and West Virginia (Alpizar-Jara et al. 2001), so we ignored this source of mortality, such that $N_{female,a,summer} = N_{female,a,spring}$. Following spring harvest, we subjected all remaining turkeys to age- and sex-specific summer mortality. We drew age- and

Table 1. Estimates of all parameters in the turkey population model to predict the consequences of the harvest regulations on the fundamental objectives of maximizing turkey population size, maximizing fall turkey observations, maximizing fall harvest opportunity, and maximizing fall harvest success in New York, USA. Status quo regulations consisted of a season length from 1 to 6 weeks and a bag limit of 1 or 2 turkeys, depending on region of the state.

		Turkey management zone			
Parameter	Harvest regulation	All	Northern	Southeastern	Western
F fall harvest rate[a,b]	Status quo		0.038–0.093	0.064–0.169	0.045–0.118
	2 weeks, 1 bird		0.017–0.079	0.017–0.079	0.017–0.079
	3 weeks, 1 bird		0.037–0.090	0.037–0.090	0.037–0.090
	4 weeks, 2 birds		0.047–0.116	0.047–0.124	0.047–0.124
	7 weeks, 2 birds		0.064–0.169	0.064–0.169	0.064–0.169
Juvenile M spring harvest[d]	All		0.131–0.141	0.130–0.140	0.163–0.174
Adult M spring harvest[d]	All		0.318–0.361	0.330–0.350	0.388–0.415
Poults/female (SD)[a]	All		2.46 (0.68)	2.71 (0.54)	2.54 (0.47)
Days $\geq$38.1 cm snow (SD)[f]	All		30.79 (19.71)	11.49 (13.83)	5.73 (12.67)
Density (no./miles^2)[a]	All		2.0–4.0	6.9–9.2	9.0–13.0
M fall harvest rate[c]	All	0.090–0.110			
Juvenile F winter survival[b]	All	0.311–0.661			
Adult F winter survival[b]	All	0.570–0.830			
Juvenile M winter survival[d,e]	All	0.891–0.935			
Adult M winter survival[d,e]	All	0.729–0.785			
F summer survival[b]	All	0.604–0.850			
Juvenile M summer survival[d,e]	All	0.907–0.939			
Adult M summer survival[d,e]	All	0.823–0.847			

[a] New York State Department of Environmental Conservation (NYSDEC) data (1997–2012).
[b] D. R. Diefenbach (U.S. Geological Survey, unpublished data).
[c] D. R. Diefenbach (unpublished data).
[d] Calculated from Diefenbach et al. (2012).
[e] Rolley et al. (1998).
[f] NYSDEC data (1988–2013).

sex-specific summer survival rates randomly each year of the simulation from a set of uniform distributions of rates estimated from tagging studies of male turkeys in New York (Diefenbach et al. 2012) and female turkeys in Pennsylvania (D. R. Diefenbach, unpublished data; Table 1). For male turkeys, we calculated the proportion of the annual survival that occurred in each season in a study of male turkeys in Wisconsin (Rolley et al. 1998) and applied that proportional survival to the age-specific annual survival estimates for New York (Diefenbach et al. 2012). Summer survival of each individual was the product of a Bernoulli trial in which the age-specific survival rate ($\widehat{s}$) was the probability of survival:

$$N_{i,a,fall} = binom\left(N_{i,a,summer}, \widehat{s}_{i,a,summer}\right)$$

We represented productivity in the model as counts of poults per female in August of each year; all females that survived the summer mortality event were included in the estimate of productivity (R). We drew the yearly count of poults/female from a truncated normal distribution with a TMZ-specific mean (μ_r) and standard deviation (σ_r) calculated from August poult count data collected throughout New York State (1997–2012; Table 1):

$$R = N(\mu_r, \sigma_r), \text{where} R \in [0, \infty]$$

We decreased the average number of poults/female in each zone to match the rate of decline in turkey abundance after 5 years of simulation that was observed in any of the TMZs in New York (similar to methods of Alpizar-Jara et al. 2001).

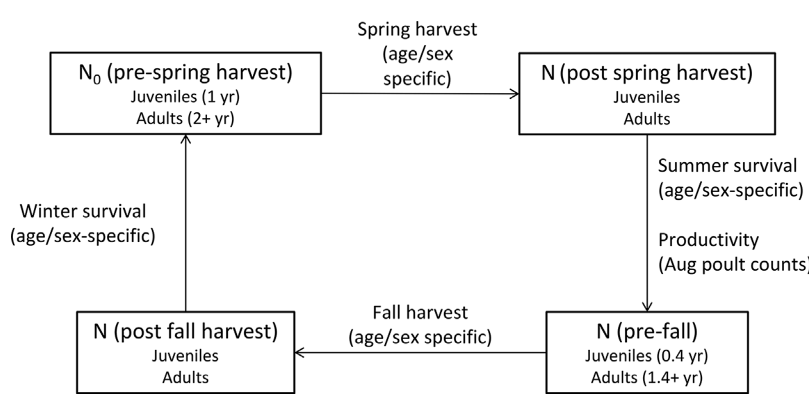

Figure 2. Schematic of the turkey population model used to evaluate the consequences of each harvest regulation on the the fundamental objectives to maximize the turkey population size, maximize fall harvest opportunity, and maximize fall harvest success in New York, USA.

We reduced the average number of poults/female by 0.5 in the Northern zone, 0.45 in the Southeastern zone, and 0.65 in the Western zone. We calculated the number of poults produced in each zone as:

$$N_{poult} = N_{female,summer} \times R$$

with an assumed 50:50 sex ratio of poults.

Following reproduction, poults and juveniles were advanced to the next age class:

$$N_{i,a+1,fall} = \begin{cases} N_{i,poult} \\ \sum N_{i,a,fall} \end{cases}$$

We then implemented age- and sex-specific fall harvest. For all harvest regulations, we estimated fall harvest rates of males as approximately 0.09–0.11 throughout New York State (D. R. Diefenbach, unpublished data). Fall female harvest rates varied by harvest regulation. We estimated harvest rates from the results of a 4-year study of female survival in Pennsylvania (D. R. Diefenbach, unpublished data; see below), and we adjusted those rates for changes in bag limits using fall harvest data from New York (1997–2012).

A 4-year study of female turkey survival in Pennsylvania estimated harvest rates of females fitted with reward leg bands or radio-transmitters (Buderman et al. 2014) for 2 years in 2 different management units, with either a 2-week or 3-week fall turkey season. Season lengths in each management unit switched for the last 2 years of the study. The range of harvest rates over the 4 years (for each of the 2-week and 3-week season lengths) became the status quo range of harvest rates in the original 2-week, 1-bird and 3-week, 1-bird fall season zones of New York. We used the difference in harvest rates observed upon changing the season length by 1 week to extrapolate the change in harvest rate ranges for each harvest regulation (Table 1). The results of the study in Pennsylvania closely mirrored the differences in female harvest rates observed in portions of Virginia and West Virginia with differing season lengths (~50% difference in harvest rate between 4-week and 8-week seasons; Pack et al. 1999). Preliminary harvest rates from an on-going study of female survival in New York fell within the range of harvest rates observed in Pennsylvania (M. V. Schiavone, NYSDEC, unpublished data).

We used data from New York's fall turkey harvest to determine the influences of altering bag limits on turkey harvest rates. Approximately 15–25% of the turkeys harvested in the fall in areas with a 2-bird bag limit in New York State was second bird harvest (1997–2012). We increased the harvest rates for TMZs with 1-bird limits by 15% (min. harvest rate) to 25% (max. harvest rate) to approximate the female harvest rate for a season of similar length with a 2-bird limit (Table 1). For example, a harvest rate of 0.05 in a 1-bird limit TMZ would be increased by 0.0075 (0.05×0.15) for a TMZ with a 2-bird limit. For each regulation, we drew age- and sex-specific harvest rates randomly from a uniform distribution of the range of rates predicted under each combination of season length and bag limit. Fall harvest of each individual was the product of a Bernoulli trial in which this randomly drawn harvest rate was the probability of harvest:

$$N_{i,a+1,winter} = N_{s,a+1,fall} - binom\left(N_{i,a+1,fall}, \widehat{h}_{i,a+1,fall}\right)$$

Age- and sex-specific winter mortality followed fall harvest. We estimated baseline winter survival for males in a similar manner to summer survival. We specified the baseline winter survival for females using estimates of monthly survival from females tracked in the 4-year study in Pennsylvania described above (Table 1). We drew age- and sex-specific winter survival rates from a uniform distribution of the range of these estimated rates. To simulate the effects of winter severity on turkey survival, we decreased winter survival for all turkeys by 20% in years in which there were 60 or more days with $\geq$38.1 cm snow depth (Austin and DeGraff 1975). For each year of the simulation, we drew the number of days with $\geq$38.1 cm of snow depth from a normal distribution with the mean and standard deviation calculated from TMZ-specific snow depth data from New York (1988–2013; Table 1). Winter survival of each individual was a product of a Bernoulli trial in which the winter survival rate was the probability of survival. The surviving turkeys became the pre-spring harvest abundance for the next year of the simulation:

$$N_{i,a+1,spring} = binom\left(N_{i,a+1,winter}, \widehat{s}_{i,a+1,winter}\right)$$

For each harvest alternative (i.e., regulation), we simulated the turkey population for 5 years under status quo conditions. We implemented the harvest regulation and simulated the population for another 5 years (yr 6–10), including the status quo option. We calculated pre-fall harvest abundance, fall harvest numbers, and pre-spring harvest abundance as the predicted value at year 10 divided by the predicted value at year 5 (last year of status quo conditions), to estimate a change in each attribute after 5 years of regulation implementation. We simulated 1,000 replicates of the stochastic model per alternative management strategy.

Predicting hunter conflict.—We measured potential conflict with other hunters (objective: minimize conflicts with other hunters) on a constructed utility scale. We used the direct rating method to elicit the expert opinion of NYSDEC biologists, in which we asked experts to rank each regulation and provide relative scores (Goodwin and Wright 2009, Cochrane et al. 2012), and the modified Delphi approach, which allowed experts to discuss their initial results (Kuhnert et al. 2010). For each of the TMZs, we provided information about the current amount of hunter effort and asked the experts to rank each regulation in terms of relative amount of hunter conflict that they expect would occur in that zone. We asked the experts to provide a score (0–100) that reflected how much difference in conflict they would expect among regulations. We provided the anonymous results to all experts for discussion, including their motivations for their own set of scores. Based on this discussion, the experts made changes if they desired. The average of final scores were normalized to a 0–1 utility scale.

Predicting fall observations of turkeys.—The objective to maximize fall observations of turkeys describes the value that hunters placed on the perception that turkeys are abundant on the landscape. However, actual turkey abundance does not correlate perfectly with perception of turkey abundance because of environmental and ecological factors like mast availability (Steffen et al. 2002) and social factors like hunter access to areas of greatest turkey density. To measure perception of turkey abundance, we created a set of TMZ-specific linear regressions that used annual spring turkey harvest numbers (the index of abundance in New York) to predict turkey observations recorded by deer hunters during the archery-only white-tailed deer hunting season (1999–2012) the following fall (an index of fall turkey abundance). With these linear models, we used the expected spring harvest from the population model to predict turkey observations the following fall for each zone.

Tradeoffs

In the tradeoffs step of SDM, tradeoffs are made among the multiple objectives within a decision problem because often no one alternative management action will best achieve all of the objectives. These tradeoffs are made according to stakeholders' values. We elicited tradeoffs in the case of fall turkey harvest in New York via a statewide hunter survey and through a direct rating exercise with NYSDEC biologists and managers.

We implemented a statewide fall turkey hunter survey to obtain information specific to our SDM project (Supplemental Material A, available online in Supporting Information). This survey instrument contained a series of rating and ranking questions that allowed us to calculate weights for the fundamental objectives of hunter satisfaction and the measurable attributes that comprised the fall hunting opportunity objective. We mailed this survey instrument to a stratified random sample of 6,250 turkey hunters throughout New York State (Supplemental Material B, available online in Supporting Information; Siemer et al. 2014).

We used the rank-order centroid method (Edwards and Barron 1994, Goodwin and Wright 2009) and the TMZ-specific results of the ranking portion of the survey (Supplemental Material B; Siemer et al. 2014) to calculate the weights on the hunter satisfaction fundamental objectives. The rank-order centroid method assumes that the differences among weights assigned to the highest-ranked objectives are greater than the differences among the weights assigned to objectives ranked lower (Hajkowicz et al. 2000). We calculated the rank-order centroid weights (w_k) as

$$w_k = \left(\frac{1}{K}\right)\sum_{i=k}^{k}\left(\frac{1}{r_i}\right)$$

where K is the number of objectives and r_i is the rank of the *i*th objective (Edwards and Barron 1994). We calculated these weights for each survey respondent and averaged the resulting weights across all respondents within each TMZ.

We used the rating portion of the survey to calculate weights on the 2 measurable attributes for the fall hunting opportunity fundamental objective. For each TMZ, we averaged the scores among respondents for the questions related to season length and the scores for the questions related to bag limit, to create a composite score for each attribute. We summed the resulting composite scores and divided the composite score for each attribute by the summed score to determine the attribute weights. We used the weights and normalized measurable attributes (0–1) to calculate a weighted index of hunting opportunity under each harvest regulation (Gregory et al. 2012).

Turkey biologists and managers from NYSDEC provided weights on the overarching fundamental objectives of hunter satisfaction and turkey population growth. Each individual had 10 points to allocate between the 2 objectives. The group then discussed the weights supplied by each individual and agreed upon a consensus weight, which we scaled to 0–1, (0.6 on the turkey population and 0.4 on hunter satisfaction).

We used an additive multi-attribute utility function to calculate the expected utility value $E(U)$ for each regulation (Keeney 1992, Gregory et al. 2012). This utility function was simply a weighted average of the utility scores for each of the individual objectives, weighted according to stakeholder values:

$$\begin{aligned}E(U) = {} & w_{\text{DEC}} \times U_{Population} + w_{\text{DEC}}(w_{\text{Hunters}} \times U_{Conflicts} \\ & + w_{\text{Hunters}} \times I_{HuntingOpportunity} + w_{\text{Hunters}} \times U_{Observations} \\ & + w_{\text{Hunters}} \times U_{HarvestOpportunity} + w_{Hunters} \times U_{HarvestSuccess})\end{aligned}$$

where w_{DEC} was a weight provided by NYSDEC and w_{Hunters} was a weight calculated from hunter survey data. Each U was a utility score for a measurable attribute, and the I was the weighted index of hunting opportunity. Each of these utility scores must be on the same scale before calculating the expected utility values, so the weights assigned to each objective are interpreted correctly. We normalized the consequences for each objective to a 0 to 1 scale to allow for direct comparisons among objectives. We initially created the utility scale for the hunter conflict objective so that the best performing alternative (i.e., the alternative that best minimized conflict) received a 0. We transposed this utility scale before inclusion in the utility function, so that the best performing alternative for each objective was scored as 1. We determined that the regulation with the greatest expected utility value for each TMZ was the optimal fall turkey harvest regulation for that zone.

We evaluated the sensitivity of the decision in each TMZ to uncertainties in turkey population demographics in 2 ways. We calculated the expected utility value for each TMZ under the mean, 25th, and 75th percentile outputs from the population model. This sensitivity analysis is similar to the process of downside reporting described in Gregory et al. (2012). In addition, in some TMZs, especially the Northern zone, spring harvest was not a good predictor of fall observations, so we evaluated the sensitivity of our decision in each TMZ by calculating the expected utility value with the observations predicted using the upper and lower bounds of the 95% confidence intervals of the slope and intercept of the models.

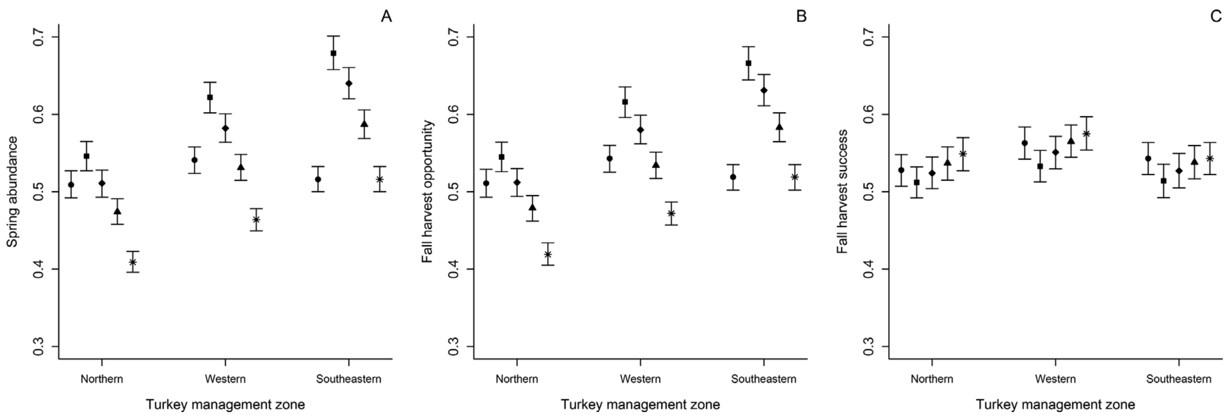

Figure 3. Consequences for the measurable attributes of the fundamental objectives to (A) maximize turkey population size (spring abundance), (B) maximize fall harvest opportunity, and (C) maximize fall harvest success for the fall turkey harvest management in New York, USA, decision problem. Values are the average and 95% confidence intervals of 1,000 simulations of the turkey population model for each turkey management zone, after 5 years under each harvest regulation (simulation year 10), divided by the value at year 5 of the simulation (last year of status quo), providing an estimate of the change in the attribute after 5 years under each regulation. Harvest regulations are status quo (circles), 2-weeks, 1-bird (squares), 3-weeks, 1-bird (diamonds), 4-weeks, 2-birds (triangles), and 7-weeks, 2-birds (stars).

RESULTS

Consequences

Our population model was designed to predict continued declines in abundance in all TMZs after 5 years under status quo (i.e., current) harvest regulations ($\bar{x} = 46$–49% decline; 12,454–39,899 fewer birds; Fig. 3, Table S3, available online in Supporting Information). Although abundances in each zone continued to decline under all management regulations, the average decline in abundance after 5 years was least under the 2-week, 1-bird regulation ($\bar{x} = 32$–45% decline; 11,460–27,752 fewer birds) and greatest under the 7-week, 2-bird regulation ($\bar{x} = 54$–59% decline; 15,067–39,889 fewer birds; Fig. 3, Tables S3 and S4, available online in Supporting Information). Implementing the 2-week, 1-bird regulation, compared to status quo, resulted in 995 (Northern Zone) to 14,006 (Southeastern Zone) more turkeys on the landscape after 5 years (Table S3). The predicted 25th percentile declines in abundance were 66–70% under status quo, 58–68% under the 2-week, 1-bird regulation, and 68–75% under the 7-week, 2-bird regulation (Table S5, available online in Supporting Information). The predicted 75th percentile declines in abundance were 32–35% under status quo, 15–30% under the 2-week, 1-bird regulation, and 35–47% under the 7-week, 2-bird regulation (Table S6, available online in Supporting Information). Likewise, average fall harvest opportunity ($\bar{x} = 46$–49% decline) and predicted fall harvest ($\bar{x} = 44$–47% decline) continued to decline after 5 years under status quo harvest regulations. Fall harvest opportunity after 5 years was lowest under a 7-week, 2-bird season ($\bar{x} = 48$–58% decline) and greatest under the 2-week, 1-bird regulation ($\bar{x} = 33$–45% decline). Our population model predicted that fall harvest success would be lowest under the 2-week, 1-bird regulation ($\bar{x} = 47$–49% less after 5 years) and greatest under the 7-week, 2-bird regulation ($\bar{x} = 42$–46% decline after 5 years; Fig. 3; Tables S4–S6). Similar to harvest opportunity, predicted fall observations increased with decreasing season length (Table S7, available online in Supporting Information).

Expected hunter conflict differed among the TMZs. In the Southeastern and Western zones, the experts predicted that hunter conflict would increase as season length decreased (Fig. 4). In the Northern zone, experts predicted that hunter conflict would be lowest in the 3-week, 1-bird season because the 4- and 7-week regulations would coincide with the hunting season for white-tailed deer. Turkey and white-tailed deer seasons would not overlap in the Southeastern and Western zones.

Tradeoffs

Across all zones, hunters placed the least amount of weight on hunter conflicts (Table 2). In the Northern and Western zones, hunters most valued fall turkey observations, followed closely by fall hunting opportunities. Hunters in the Southeastern zone valued fall hunting opportunities slightly more than turkey observations. Within the fall hunting opportunity objective, hunters statewide placed more value

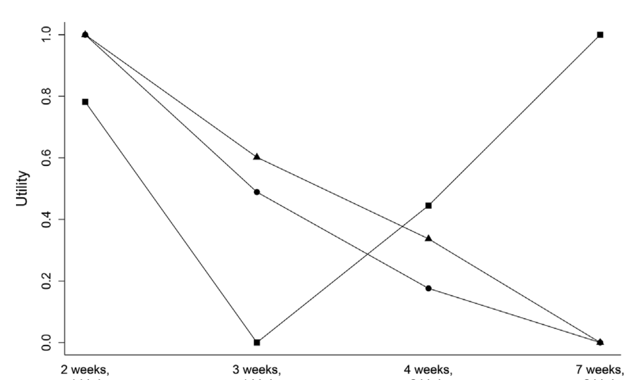

Figure 4. Utility scores for the objective of minimizing conflict with other hunters under each harvest regulation for the Northern (squares), Southeastern (triangles), and Western (circles) turkey management zones in New York, USA. Each regulation is a combination of season length (weeks) and bag limit (no. birds). Regulations with the greatest expected hunter conflict receive a utility score of 1, and regulations with the least expected hunter conflict receive a score of 0.

Table 2. Weights for each of the fundamental objectives related to hunter satisfaction for each turkey management zone in New York, USA, 2013.

	Turkey management zone		
Fundamental objective	**Northern**	**Southeastern**	**Western**
Minimize conflicts with other hunters	0.141	0.137	0.127
Maximize fall hunting opportunity	0.250	0.276	0.223
Maximize fall turkey observations	0.255	0.257	0.278
Maximize fall harvest opportunity	0.193	0.181	0.216
Maximize fall harvest success	0.161	0.149	0.157

on season length (weight = 0.560–0.602) than on bag limit (weight = 0.398–0.440).

In all TMZs, the optimal harvest regulation was the 2-week, 1-bird regulation. Maximizing the turkey population was the most influential objective in the decision model (Fig. 5 and Table 3). The second most influential objective was fall hunting opportunity, which would be best achieved with the 7-week, 2-bird regulation (Fig. 5 and Table 3). The optimal decision (2-week, 1-bird) performed best for 3 (maximize turkey population size, maximize fall harvest opportunity, and maximize fall turkey observations; except in the Northern Zone), of the 6 objectives, and was worst at achieving the other 3 objectives (maximize fall harvest success, minimize conflicts with other hunters, maximize fall hunting opportunity). The optimal decision was robust to the use of the 25th or 75th percentile outputs from the population model (Tables S5 and S6) and the 95% confidence interval predictions of turkey observations in

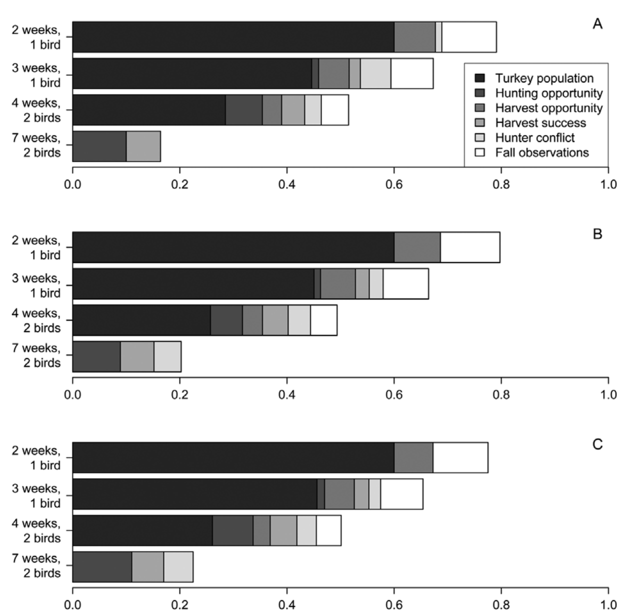

Figure 5. Expected utility value of each regulation (season length, bag limit) of the fall turkey harvest decision problem, broken down by objective, for the (A) Northern, (B) Western, and (C) Southeastern turkey management zones in New York, USA.

each TMZ (Table S7). In all cases of uncertainty evaluation, the expected utility values did not differ from the values calculated with the average model outputs.

DISCUSSION

This case study represents the first use of SDM to develop wild turkey harvest management plans. Structured decision making is very useful for natural resources management (Gregory et al. 2012, Conroy and Peterson 2013), but there are still very few examples of the use of SDM for wildlife management (Robinson et al. 2016, Sells et al. 2016). In our case study, SDM provided a framework to describe the values of stakeholders and predict the consequences of proposed harvest regulations on each of these values. The SDM process maximized the transparency of the decision process by allowing managers to explicitly state what factors were considered when setting harvest regulations and allowed for a formal analysis, thereby reducing the potential for disagreement among stakeholders or with the management agency. The SDM approach we described here can be used to address natural resource management problems, providing a documented process that can be repeated over time, perhaps resulting in a better understanding of the effect of changes in harvest regulations on population dynamics.

The results of our decision analysis for fall turkey harvest in New York highlight one of the most important aspects of the SDM process: the ability to make difficult tradeoffs among multiple competing objectives (Keeney 1992, Gregory et al. 2012). Most often, no one alternative management action will best satisfy all of the objectives. This was the case for fall turkey harvest, in which the optimal regulation (2-week, 1-bird), performed the best for 3 of the 6 objectives and performed worst for the other 3 objectives. Stakeholders placed the greatest value (i.e., objective weights) on the objectives related to turkey availability and population size. Along with the predicted consequences, or outcomes, of the harvest regulation for these objectives, the set of objective weights used in the multi-attribute utility function led to the 2-week, 1-bird season being optimal. Predicting the consequences of each of these harvest regulations on each of the objectives is very important in the process of SDM. However, understanding how the relevant stakeholder groups value these outcomes, in the tradeoffs stage, provides the means for arriving at the final decision (Riley and Gregory 2012).

The optimal regulation (2-week, 1-bird) provided the best balance between turkey population size, fall turkey observations, and fall harvest opportunity among the 4 regulation packages considered. Based on the long-term trend of apparent declines in turkey abundance observed in New York, as indicated by a decline in spring harvest, our model predicted that turkey abundance would continue to decline under all harvest regulations. However, declines in abundance were predicted to be slowest under the 2-week, 1-bird regulation. As compared to the status quo (i.e., current) regulations, the 2-week, 1-bird regulation would slow declines in abundance by 7% in the Northern Zone, 15% in the Western Zone, and 32% in the Southeastern Zone, on average. The differences among zones in declines in abundance are a function of the current

Table 3. Consequence tables for the fall turkey harvest management in New York, USA, decision problem for each turkey management zone. Values for each objective represent the normalized consequences of each set of harvest regulations (alternative; season length, bag limit) on that objective. We used weights in the multi-attribute utility model to calculate the weighted average ($E(U)$ = expected utility value) of each alternative harvest regulation. DEC = New York Department of Environmental Conservation. We normalized all consequences to a 0–1 scale, where 1 is best and 0 is worst. The alternative in each zone with the greatest $E(U)$ is the optimal alternative.

				Alternative					
Zone	**Overarching fundamental objective**	**Hunter satisfaction fundamental objective**	**Measurable attribute**	**2 weeks, 1 bird**	**3 weeks, 1 bird**	**4 weeks, 2 birds**	**7 weeks, 2 birds**	**Weights from hunters**	**Weights from DEC**
Northern zone									
	Max. turkey hunter satisfaction	Min. conflicts with other hunters	Utility scale- change in conflict	0.218	1.000	0.555	0.000	0.141	0.4
		Max. fall hunting opportunity	Weighted index- days and bag limit	0.000	0.127	0.693	1.000	0.250	
		Max. fall turkey sightings or hearings	Predicted bow hunter sightings	1.000	0.769	0.500	0.000	0.255	
		Max. fall harvest opportunity	Number of turkeys harvested relative to status quo	1.000	0.742	0.473	0.000	0.193	
		Max. fall harvest success	Number of turkeys available relative to status quo	0.000	0.331	0.673	1.000	0.161	
	Max. turkey population size		Spring turkey abundance relative to status quo	1.000	0.743	0.476	0.000		0.6
	E(*U*)			0.792	0.672	0.517	0.164		
Southeastern zone									
	Max. turkey hunter satisfaction	Min. conflicts with other hunters	Utility scale- change in conflict	0.000	0.398	0.663	1.000	0.137	0.4
		Max. fall hunting opportunity	Weighted index- days and bag limit	0.000	0.128	0.689	1.000	0.276	
		Max. fall turkey sightings or hearings	Predicted bow hunter sightings	1.000	0.771	0.451	0.000	0.257	
		Max. fall harvest opportunity	Number of turkeys harvested relative to status quo	1.000	0.764	0.439	0.000	0.181	
		Max. fall harvest success	Number of turkeys available relative to status quo	0.000	0.458	0.835	1.000	0.149	
	Max. turkey population size		Spring turkey abundance relative to status quo	1.000	0.760	0.435	0.000		0.6
	E(*U*)			0.663	0.601	0.534	0.337		
Western zone									
	Max. turkey hunter satisfaction	Min. conflicts with other hunters	Utility scale- change in conflict	0.000	0.511	0.824	1.000	0.127	0.4
		Max. fall hunting opportunity	Weighted index- days and bag limit	0.000	0.136	0.670	1.000	0.223	
		Max. fall turkey sightings or hearings	Predicted bow hunter sightings	1.000	0.763	0.447	0.000	0.278	
		Max. fall harvest opportunity	Number of turkeys harvested relative to status quo	1.000	0.754	0.433	0.000	0.216	
		Max. fall harvest success	Number of turkeys available relative to status quo	0.000	0.411	0.764	1.000	0.157	
	Max. turkey population size		Spring turkey abundance relative to status quo	1.000	0.751	0.429	0.000		0.6
	E(*U*)			0.797	0.664	0.494	0.203		

season structure; we observed the greatest response in the Southeastern Zone where the season decreased from 7 weeks to 2 weeks (32% change from status quo), and the smallest response in the Northern Zone where there was a modest 1-week reduction in season length (7% change from status quo). Although not a specific objective of this SDM process, the spring hunting season also would be positively affected by the shorter fall season; the slower decline in abundance would be realized as an increase in the number of turkeys on the landscape prior to the spring season.

Although the optimal regulation (2-week, 1-bird) best achieved the fundamental objective of maximizing the turkey population, we found that manipulation of fall harvest regulations would not completely reverse the apparent declines in turkey abundance. The small expected reduction in female harvest rates, relative to status quo, was not enough to mitigate the negative growth rate that wild turkeys appear to be experiencing in New York. This was especially evident in the Northern zone, with a status quo season length of 3 weeks. Even in the Southeastern zone, which would undergo a 5-week reduction in season length, we still predicted turkey abundance would decline under the optimal harvest regulations. Although a closed fall season was not included in our decision analysis as a viable alternative, the population model predicted that turkey abundance would continue to decline even if the fall season were closed. Reducing the harvest rate of female wild turkeys in the fall still would have a noticeable effect on wild turkey abundance in New York, especially compared to the current fall regulation structure. Fall harvest regulations are one of the fundamental aspects influencing wild turkey abundance over which wildlife managers have some control (Vangilder and Kurzejeski 1995, Healy and Powell 1999). The SDM process helped wildlife managers consider the multiple objectives of stakeholders to allow important tradeoffs to be explicit when setting these fall harvest regulations.

A subjective, or *ad hoc*, approach to decision making for fall turkey harvest regulations likely would have arrived at a similar conclusion as this case study: reducing the season length reduced harvest of female turkeys, which would reduce the rate of decline in abundance. However, we believe that decisions should be evaluated by the quality of the process, not just by the outcome (Jones and Bence 2009). Structured decision making allowed for a formal evaluation of the uncertainty in turkey population demographics that might influence our decision and provided predictions of consequences that are specific to the objectives of stakeholders. Decisions often are mired by uncertainties that could influence the outcomes, particularly for species like turkeys, which undergo large fluctuations in abundance from year to year (Mosby 1967, Healy and Powell 1999). By evaluating the effects of uncertainty in the population model estimates of abundance on the optimal decision, we found that our decision was robust to these large fluctuations in abundance. In addition, implementing a structured process in which we specifically predicted how management actions would affect a set of fundamental objectives showed how stakeholders valued fall turkey hunting and how potential regulations would achieve those values. For example, the results of our study indicated that reducing fall turkey harvest to a 2-week season would not reverse the apparent decline in turkey abundance in New York. The range of harvest rates that we used for the 2-week, 1-bird season in our population simulation model was less than the 10% rule of thumb suggested by Vangilder and Kurzejeski (1995) and the 9% maximum suggested by McGhee et al. (2008), indicating that other aspects of turkey ecology, such as reduced productivity (Casalena et al. 2016), likely are influencing the observed declines in abundance. We also learned that fall turkey hunters in New York placed a greater value on the ability to go afield during the fall and to see turkeys on the landscape than on harvesting a turkey. Based on this information, a new season structure in New York was devised in which the fall seasons in the 3 TMZs do not overlap. With this structure, hunters can still hunt for turkeys for a maximum of 6 weeks in the fall.

The SDM process in our case study for fall turkey harvest management provided valuable information to the state wildlife agency about ecological and social aspects of fall turkey hunting. In addition to determining that fall harvest regulation changes can lessen, but not eliminate, the decline in turkey abundance, we learned about hunters' preferences for a satisfying fall turkey hunting experience. The results of the SDM process provided information about a set of fall harvest regulations that incorporated concerns about declines in turkey abundance throughout the state and the values of fall turkey hunters in New York.

MANAGEMENT IMPLICATIONS

We were able to evaluate how key uncertainties about wild turkey demographics in New York would affect our decision when some objectives were competing and could not be maximized (e.g., maximizing the turkey population and maximizing fall hunting opportunity). The tradeoffs step explicitly acknowledged that certain objectives were valued more than others. Structured decision making provided a transparent, robust, and repeatable process for making decisions about wild turkey hunting regulations.

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