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Managing the vanishing North American hunter: a novel framework to address declines in hunters and hunter-generated conservation funds

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ABSTRACT

As long as the funding mechanism supporting state wildlife conservation relies heavily on hunter-generated funds, declines in hunter participation are a threat to the conservation of both game and nongame species. To address options to bolster wildlife agency profit from the sale of hunting licenses, we developed a stage-based, stochastic population model of a hunter population, and demonstrate its utility within a decision-making framework to inform state wildlife agency decisions. We evaluated hypothetical youth and adult recruitment-focused outreach programs over 10 years to increase license sale profit. Using our model as the core of a decision analysis, state agencies can set hunter population or license profit targets, and evaluate management actions designed to achieve those objectives. We expect that our approach will provide a valuable framework for anticipating the future of hunting and hunting-generated conservation funds, and can be extended to other user groups, including target shooters and anglers.

Introduction

Documented declines in both the number of hunters and percentage of hunters relative to the total U.S. population (United States Fish and Wildlife Service, 2016) poses a potential threat to the societal benefits afforded by hunting. One of the most salient consequences of declining hunter populations is its threat to the funding mechanism supporting wildlife management in North America. In the United States, state wildlife agencies have the fiduciary responsibility of managing wildlife resources in the public trust (Geist, 1995; Geist, Mahoney, & Organ, 2001). Historically, the primary mechanism funding wildlife management has been a user-pay system, in which monies are leveraged from consumptive (i.e., hunters, trappers, anglers) and nonconsumptive users (i.e., nonhunting sport shooters, boaters) to fund state wildlife agency activities (Jacobson, Organ, Decker, Batcheller, & Carpenter, 2010). Notably, there are other significant sources of funding generated for conservation purposes targeted from local to global scale activities (i.e., by private and nonprofit organizations). However, funds generated by consumptive and

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nonconsumptive users are the largest contributing sources for state-based wildlife conservation (Lueck, 2005; Mahoney, 2009). Hunters generate conservation funds via hunting license sales and permits, in addition to taxes levied under the Federal Aid in Wildlife Restoration Act of 1937 (16 U.S.C. 669-669i; 50 Stat. 917; commonly referred to as the Pittman-Robertson Act), via an excise tax of 11% on firearms, archery equipment, and ammunition, and a 10% tax on handguns. These funds, hereafter PR funds, are then distributed to state agencies via a federal matching program, and are earmarked for mammal and bird conservation, management, and research, as well as hunter education. While a recent survey by Southwick Associates (2017) indicates that PR funds derived from nonhunting sources (e.g., sport shooters) exceed those of hunting, the revenue from hunting licenses is also an important source of state conservation funds. Combined, license sales and federal funds sum to over $1.3 billion nationally (Southwick Associates, 2007) and, along with angler and boater-generated funds, have been estimated to account for approximately 65% of state agency budgets for wildlife (Lueck, 2005). Reductions in monies levied by these funding mechanisms may limit agency capacity to manage wildlife populations and conserve their habitats.

Concerns regarding the stagnation of hunter numbers are not new (Ryel, 1968), and significant efforts have been extended to better understand hunters and inform management. Studies have identified a wide range of factors associated with the decline in hunters, including the presence of competing priorities for an individual's time and money, lack of access to land for hunting, urbanization, changing demographics, and too many regulations (Duda, Bissell, & Young, 1995; Gude, Cunningham, Herbert, & Baumeister, 2012; Mehmood, Zhang, & Armstrong, 2003; Miller & Vaske, 2003; Robison & Ridenour, 2012; Schorr, Lukacs, & Gude, 2014). Most of these findings have come from survey-based studies that assess patterns in respondents' motivations, values, and preferences. Such surveys are critical for evaluating and garnering support for agency programs. However, predictive capacity of survey results may be limited because hunter survey responses may not match the respondents' actual behavior (Stedman et al., 2004). Studies that have projected hunter populations have generally done so by utilizing national surveys or state license sale data to estimate hunter population parameters, explore the underlying mechanisms driving population dynamics, and then apply their results to forecast and predict the future number of hunters (Bowker, English, & Cordell, 1999; Huck & Winkler, 2008; Winkler & Warnke, 2013). While these efforts provide valuable information and guidance regarding which population parameters to target to increase the number of hunters, additional approaches are needed to predict the number of hunters under multiple management alternatives that target those population parameters.

Recent efforts to inform harvest management of game species have utilized decision analytical methods, and can be extended to evaluate management alternatives available to agencies to influence hunter populations. Decision analysis is an increasingly applied paradigm to complex decision-making in wildlife and natural resource science (McGowan, Lyons, & Smith, 2015; O. J. Robinson, McGowan, & Apodaca, 2016). The paradigm offers a set of tools for breaking complex management decisions down into component parts (i.e., problem definition, management objectives, alternative actions, consequences of the actions and trade-offs assessment, and addressing these components sequentially) (Gregory & Keeney, 2002; Keeney, 1996). The primary distinction

of decision analytic approaches compared with other decision-making paradigms is a focus on the decision maker's values and objectives at the onset of the decision process, which greatly influences the succeeding components of the decision (Keeney, 1996; McGowan et al., 2015). For example, decision analysis efforts often use predictive models to assess the consequences of management actions and values of the predicted outcomes with respect to the articulated objectives (Gregory & Keeney, 2002). Hunter management has long been assimilated into harvest decisions of game species using decision analysis frameworks (Nichols, Johnson, & Williams, 1995), and has expanded to include hunter-specific objectives that maximize hunter satisfaction and minimize management costs (e.g., Robinson, Fuller et al., 2016). Applying these methods to explicitly address questions concerning hunter population dynamics and license sale profit within a decision-making framework could provide additional benefits to wildlife managers allocating resources for managing game species and hunter participation. State wildlife managers have made it a priority to improve hunting participation, and have a wide range of alternatives that could be implemented to influence hunters, such as special hunts (e.g., youth dove hunts), hunter education programs, changes to license prices, changes to game harvest regulations, and mentor programs (Responsive Management, 2011). In particular, substantial effort and funding has been directed toward outreach programs aimed at socializing and training new hunters (Ryan & Shaw, 2011). However, because there has been minimal effort to coordinate and evaluate outreach programs (Council to Advance Hunting and the Shooting Sports & Wildlife Management Institute, 2016), there is a lot of uncertainty around management decisions affecting hunter recruitment, retention, and reactivation. This uncertainty complicates management decisions concerning hunters, and highlights the need for new approaches to assess options affecting the number of hunters and license profit.

To help state wildlife agencies directly address the declining trend in hunter participation and hunter-generated conservation funds, we applied a modeling approach commonly used in wildlife population management to evaluate management actions aimed at increasing license sales, and demonstrate its utility within a decision-making framework to inform state wildlife agency decisions. We used a matrix population model to simulate a population of hunters in which each matrix element represents a population vital rate (e.g., age- or stage-specific reproduction and survival; Morris & Doak, 2002). We then simulated management actions by perturbing the parameters of the matrix (Wootton & Bell, 1992). Population models have been used in a variety of contexts including species listing decisions (e.g., McGowan, Allan, Servoss, Hedwall, & Wooldridge, 2017), harvest decisions (e.g., Robinson, Fuller et al., 2016), reserve design (e.g., Armbruster & Lande, 1993), and population management decisions (e.g., Robinson, Fefferman, & Lockwood, 2013). However, the application of population modeling within a decision-making framework has not been used to evaluate the impact of management actions directly on a hunter population or license sale profit. Our application deviates from traditional population modeling in that we do not use the model to assess the human population, but instead extend the approach to a system of license purchasers in a way that is analogous to biological population modeling. Ultimately, hunters are another population that state agencies are trying to manage, and we demonstrate how extending these methods to hunter management

decisions can improve the decision-making capacity of state wildlife agencies interested in influencing hunter and hunting license sales.

Methods

Decision-Making Framework

Structured decision-making (SDM) is a values-driven decision-making framework that has been used extensively to guide natural resource decisions (Gregory et al., 2012; Robinson, McGowan, et al., 2016), and may be a useful approach for hunter management decisions. To aid state wildlife agency declining hunter population concerns, we utilize SDM's 5-step approach for undertaking a hypothetical management decision: (a) clearly articulate the problem, (b) define the objectives, (c) determine actions available to managers to address the problem and objectives, (d) predict the consequences of the actions (frequently a modeling exercise), and (e) assess trade-offs and make a decision given the stated objectives (Gregory et al., 2012). For our hypothetical SDM process, our problem is determining how to increase hunting license sales and associated profit over time using recruitment-focused outreach programs. While we address a hunter recruitment-focused management decision, we also discuss applications of our approach to a wider range of outreach program goals (i.e., increasing retention, reactivation, or participation) and user groups (i.e., target shooters, anglers) toward the end of this paper. We focused on state license sales because, for many state wildlife management agencies, sale of hunting licenses is a primary source of revenue and funding for the agency, and these sales provide a link between state agency management and hunter-generated conservation funds. License sale data are collected annually and provide a direct measurement of changes in hunter population dynamics. We excluded Pittman Robertson (PR) funds from our analysis because PR taxes are levied from all gun and archery equipment sales, which includes many nonhunting target shooters. Further, PR tax collection and distribution remains under federal jurisdiction, precluding any state agency-directed changes to the system. However, changes in state license sales can also influence the appropriation of PR funds, especially if there are changes in the number of paid license holders in the state relative to the national total ("Wildlife restoration program apportionment formula," 2008). Modeling state license sales provides a direct link between hunters and hunter management, and state wildlife agency budgets, and could be further utilized to consider changes in PR funds.

We assumed that the objectives of a state wildlife agency relative to the decision of how to increase state license sales using recruitment programs would be to maximize state license sale profit by maximizing the license sale revenue and minimizing the cost of management. There are certainly other objectives that influence wildlife management agency hunter recruitment decisions, however, for the purpose of demonstrating the utility of SDM and projection modeling we focused solely on hunting license profit. We evaluated state-administered, recruitment-focused outreach programs to demonstrate the capacity of our approach to predict the outcome of different management scenarios on hunting license sales and profit. We chose to model recruitment-focused outreach programs because they are a common practice of state agencies, receiving a significant amount of agency funding and attention (Responsive Management, 2011; Wildlife Management Institute & D.J. Case and Associates, 2009). Given the lack of empirical

evaluations of outreach programs, we chose to model hypothetical 1-day outreach programs for youth and adults, and applied our framework to a small population (~ 10,000 individuals). While we focused on one set of potential management actions, our approach could easily incorporate other actions state agencies may consider to increase state license sale profit or address their specific objectives. We examined seven management scenarios comprised of different levels of youth (defined below) and non-license holding adult participation (hereafter adult) in the programs: (a) no outreach programs, (b) 2.5% of the total youth population in the state participating in an outreach program, (c) 5% of youth participating, (d) 7.5% of youth participating, (e) 2.5% of total non-license holding adults in the state participating in an outreach program, (f) 5% of adults participating, and (g) a combination of 5% youth and 5% adults participating. We applied a cost to the agency of $20 per youth and $20 per adult for outreach programs. We then developed a simulation model to predict and evaluate the probable effect of each of these management alternatives on a population of hunting license holders and potential license holders.

Hunter Population Model

We built a 4-stage hunter population model comprised of stages that reflect the license system in the state of Alabama, where an individual can purchase an annual or lifetime hunting license (Figure 1). Several states have similar licensing systems, but the stage structures could be modified to fit a variety of licensure systems (Caswell, 2006). We used a stage-based rather than an age-based model to allow individuals to remain in the same stage for multiple time steps, and omitted sex in our analysis for simplicity. We use biologically analogous terms that are commonplace in population modeling in our descriptions, although they do not always strictly equate to biological terms. Youth (Y) represent all individuals under the age of 16 who are not required to purchase a hunting license in Alabama. Once a youth reaches the age of 16,
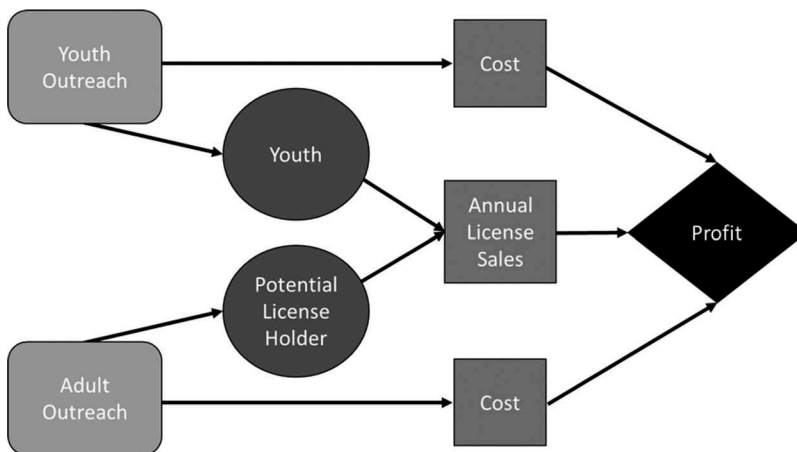
Figure 1. Influence diagram of a hunter management decision. The rounded boxes represent the alternative recruitment-focused outreach programs that can be applied to non-license holding individuals. The outreach decision affects the probability that an outreach participant (circles) will purchase an annual license. The objective of the decision is to maximize profit (diamond) by maximizing the sale of annual licenses and minimizing the cost of the outreach program (squares).

they transition into one of the three adult stages. A potential license holder (P) is ≥ 16 years of age and does not own a hunting license at a given time step. Potential license holders can remain within this stage in any subsequent time step or transition to either hunting stage with the purchase of an annual or lifetime license. An annual license holder (A) can remain an annual license holder, transition to a lifetime license holder, or revert to a potential license holder. The lifetime license holder stage (L) is an absorbing stage, and individuals remain within this stage regardless of whether they hunt in a given year. New youths are produced by the three adult age classes. We constructed the hunter population as a 4×4 matrix and multiplied it by our hunter population vector:

$$\begin{bmatrix} S_{YY} & F_P & F_A & F_L \\ S_{YP} & S_{PP} & S_{AP} & 0 \\ S_{YA} & S_{PA} & S_{AA} & 0 \\ S_{YL} & S_{PL} & S_{AL} & S_{LL} \end{bmatrix} \times \begin{bmatrix} Y_t \\ P_t \\ A_t \\ L_t \end{bmatrix} = \begin{bmatrix} Y_{t+1} \\ P_{t+1} \\ A_{t+1} \\ L_{t+1} \end{bmatrix}$$

where Y, P, A, and L represent individuals in each stage at time t, where each time step is 1 year. The subscripts on the F terms indicate the life stage for the reproduction rate, while the subscripts on the S terms, hereafter q, indicate the stage in the current time step followed by the stage in the successive time step.

Typically in population models stochastic environmental variation (stochasticity) is introduced by implementing randomized draws from statistical distributions for each model vital rate (e.g., survival, fecundity) in each year of the simulation. The survival and transition terms (S) for each matrix parameter q, each realization i, at time t, were modeled as a beta distributed random variable with parameters α_i and β_i derived from the mean survival rate, $\mu_{q,i}$, and variance, σ_{iq}, such that $S_{q,i,t} \sim beta\left(\alpha_{q,i},\ \beta_{q,i}\right)$.

The reproduction terms (F) were modeled as random variables drawn from a uniform distribution, such that $F_{q,i,t} \sim uniform\left(\gamma_{q,i},\ \rho_{q,i}\right)$, where $\gamma_{q,i}$ and $\rho_{q,i}$ are the minimum and maximum fecundity values. Wildlife population models frequently use a lognormal or stretched beta distribution, however we used a uniform distribution that allowed us to include uncertainty in the values without making assumptions on the shape of the distribution of reproductive value for humans. Future applications of the model could apply alternative distributions from which to draw vital rates; however, here our goal is to demonstrate the SDM process so we did not delve deeply into parameter estimation.

A simplifying assumption of our model is that no senescence occurred in the breeding capabilities of adults in the population. However, accounting for decreased fecundity with age would simply require adding additional adult stages to the population matrix, where P, A, and L no longer have an associated fecundity term.

Modeling Outreach

We modeled the effect of outreach on our youth assuming elevated transition rates for youth to annual license holder for outreach participants compared to individuals that did not participate in an outreach program. We calculated an average transition rate from youth to annual license holder (S_{YA}), weighted by the proportion of the youth that participated in an outreach programs (P_{YO})

$$S_{YA} = P_{YO}S_{YA}^{O} + (1 - P_{YO})S_{YA}^{N},$$

where P_{YO} represents the proportion of youth outreach participants as indicated by the particular management scenario (see above), S_{YA}^{O} is the transition rate from youth to annual license holder for outreach participants, S_{YA}^{N} is the transition rate from youth to annual license holder for non-outreach individuals. Given the lack of data to accurately estimate the change in transition rates resulting from youth or adult outreach programs (Council to Advance Hunting and the Shooting Sports, & Wildlife Management Institute, 2016), we used reasonable values to populate our model. We assumed that the rate of transition from youth to annual license holder was .3 for youth outreach participants.

The rate of transition from youth to potential license holder, S_{YP}, is modeled as a function of the transition rate of youth to annual license holders subtracting the difference between S_{YA} and S_{YA}^{N} from the transition rate of youth to the potential license holder stage without youth outreach (S_{YP}^{N})

$$S_{YP} = S_{YP}^{N} - (S_{YA} - S_{YA}^{N}),$$

where S_{YP} is the transition rate of youth to potential license holder adjusting for outreach. We constrained all youth transition probabilities to sum to 1. We set a ceiling on the rate of youths transitioning into the annual license holder class to represent the maximum rate of youths transitioning into the annual license holder class. This ceiling rate reflects the reality that most youth will not turn 16 and require a hunting license in order hunt in a given year ($S_{YY} \approx .928$, $S_{YA} \leq .06$).

Similarly, we modeled the effect of outreach on potential license holders using a weighted average and then subtracted the difference in rate from the retention of potential license holders

$$S_{PA} = P_{PO}S_{PA}^{O} + (1 - P_{PO})S_{PA}^{N} \ and \ S_{PP} = S_{PP}^{N} - (S_{PA} - S_{PA}^{N}),$$

where P_{PO} represents the proportion of potential license holder outreach participants as indicated by the particular management action (see above), S_{PA}^{O} the transition rate from potential to annual license holder for outreach participants, S_{PA}^{N} the transition rate from potential to annual license holder for non-outreach individuals, and S_{PP} the survival/retention rate of potential license holders adjusting for outreach. The superscript, when used, indicates whether the rate is for outreach participants, O, or individuals that did not participate in outreach, N. We assumed that the rate for potential license holders transitioning to the annual license holder stage would increase from .02 to .6 for individuals participating in outreach.

Density Dependence of Annual License Holders

To demonstrate the capacity for our modeling framework to incorporate additional sources of complexity, we modeled the retention of annual license holders ($S_{AA,t}$) as a density dependent function, assuming that hunter abundance is a surrogate for density given relatively constant land area available for hunting each year. This component reflects evidence that crowded hunting areas are undesirable to hunters (Enck, Swift, & Decker, 1993; Hammitt, McDonald,

& Noe, 1989; Heberlein, 2002; Wright & Kaiser, 1986), and thus crowding in 1 year may lead to fewer hunters in the successive year. We modeled this overcrowding hypothesis using a logistic model, such that the retention of annual license holders is weakly influenced by the number of annual license holders in the previous year.

We parameterized the model using multiple sources (URL to online supplemental materials provided at the end of the manuscript), then modeled the influence of each management scenario on the population over 10 years with 10,000 iterations. Uncertainty and unpredictability are often considered impediments to decision-making, but decision analysis allows managers to directly incorporate uncertainty into consequence models. In order to demonstrate the capacity of our model to account for uncertainty and stochasticity within the framework of a decision analysis, we incorporated temporal variability into model parameters to represent environmental stochasticity, and we incorporated parametric uncertainty into our model using the hierarchical approach described by McGowan, Runge, and Larson (2011). Because model parameters are usually estimated from data, they are estimated with imprecision due to sampling variance so incorporating parametric uncertainty is usually an important step. This approach uses a sequential process that first draws a value for each population vital rate (i.e., model parameter) for each replicate of the simulation. We then use those replicate level parameter values to establish replicate specific distributions and use those distributions to draw parameter values for each vital rate in each year of the simulation (see McGowan et al., 2011 for more detail). For every simulation replicate we drew the shape parameters for survival and transition rates from a beta distribution, and variance shape parameters, σ_i, was drawn from an inverse Gaussian distribution with mean, m_q, and shape parameter, υ_q, such that $\sigma_{q,i} \sim IG(m_q, \upsilon_q)$.

We ran the model using the parallel simulations method outlined by Robinson, Lockwood, Stringham, and Fefferman (2015), which produces identical values for matrix elements across simulation scenarios, except where the modeled management action changes the value of an element. This allows us to isolate the effects of management alternatives as the only source of variation in each scenario. For our starting population, we assumed a stable stage distribution, calculated from the "do nothing" alternative in order to avoid unusual dynamics for the first several time steps (Caswell, 2006). We calculated the stable stage distribution and the population growth rate in R using the "popbio" package (Stubben & Milligan, 2007). We then added 25% more annual hunters to the starting population to reflect the observed decline in hunting. For each scenario and across all realizations we estimated the mean hunter abundance for each year, the cost of management, revenue from license sales, and profit, expressed as net present value. Net Present Value (NPV) is commonly used in economic analyses to account for the diminished value of profit in the future relative to the present, such NPV = (Total revenue from license sales–Total cost of management)/$(1 + .05)^t$, where .05 represents a 5% discount rate (Conrad, 2010). Finally, we evaluated each management scenario using the mean estimated NPV over 10 years.

We conducted sensitivity analyses to explore the influence of various model parameters on the decision (Conroy & Peterson, 2013), including analyses of the outreach cost parameters, recruitment of youth and adult outreach participants. We conducted a two-way profile analysis on the cost of adult outreach and recruitment of adult outreach participants, and the cost of youth outreach and the recruitment rate of youth outreach participants, varying the cost of outreach between $10 and $50, and the recruitment rates between 0 and 1.

Results

The stable stage distribution of the starting population was 16% youth, 79% potential license holders, 4% annual license holders, and 3% lifetime license holders. After adding 25% additional annual license holders, we started our simulations with a mean population of 1,636 youth, 7,842 potential license holders, 584 annual license holders, and 51 lifetime license holders (10,113 total individuals). Under the "do nothing" scenario, the growth rate of the total population was 1.003, while the growth rate of annual hunters was .98.

Our model predicted that the adult outreach program with 5% participation would result in the greatest NPV over 10 years, with scenario results ranging from $74,409 for 7.5% youth outreach to $214,381 for 5% adult outreach (Figure 2). The number of annual license sales increased from 584 in year 1 for all scenarios to 1,160 licenses per year for the 5% adult outreach scenario. While the status quo alternative, assuming the stable stage
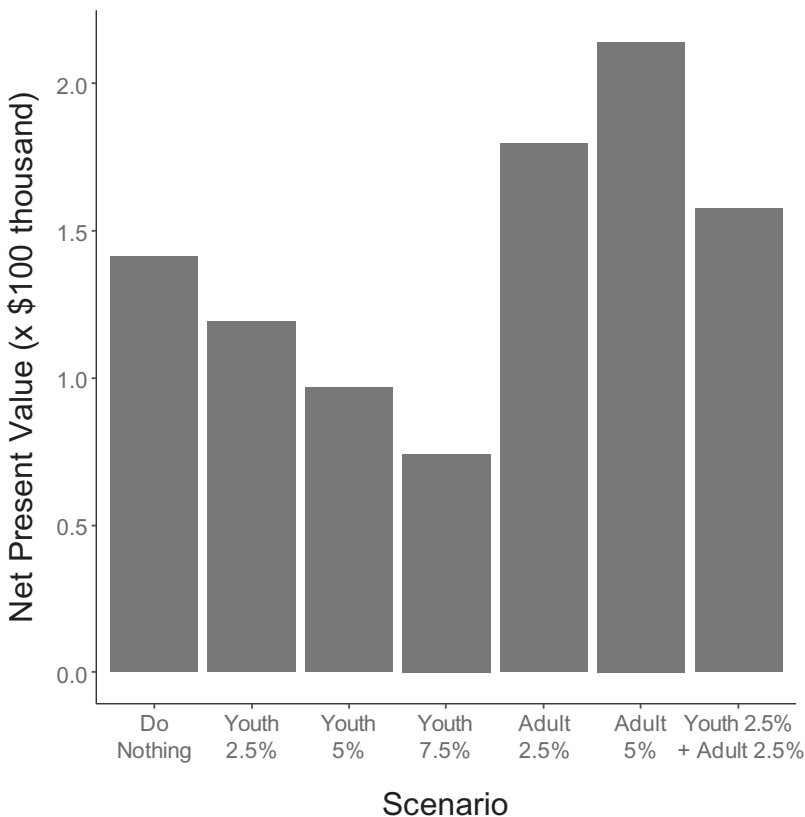

Figure 2. Predicted mean net present value (NPV) generated by each management scenario over 10 years and 10,000 model realizations. The management actions were simulated using a 4-stage matrix population model with youth, potential hunting license holder, annual license holder, and lifetime license holder stages. Management scenarios consisted of a "do nothing" alternative, and varying levels of youth and adult outreach. Adult outreach was targeted at individuals in the potential license holder stage. Net present value represents license sale profit, taking into account a 5% discount rate over time, t, such that NPV = (Total revenue from license sales−Total cost of management)/ $(1 + .05)^{t})$.

distribution, predicted that the percentage of the total population holding a hunting license would decline from 6% in year 1 to 5% in year 10, the 5% adult outreach scenario reached an average of 9% in year 10. Adult outreach cost an average of $3,927 per year for 2.5% of adult non-license holder participation and $7,636 for 5% participation.

The scenarios simulating youth outreach were predicted to be poorer alternatives than the status quo given the objectives. While alternatives employing youth participation increased license sales and revenue, the cost reduced the total NPV for all youth outreach scenarios relative to the "do nothing" scenario. The mean revenue generated per year from license sales under the youth outreach-only scenarios ranged from $16,612 with 2.5% youth participation to $18,362 with 7.5% youth participation, (Figure 3). The mean annual cost of youth outreach was $3,360 for 2.5% of youth participating in an outreach program, $6,717 for 5% youth participation, and $10,078 for 7.5% youth participation. The combination of adult and youth participation resulted in an average of $24,810 per year in revenue and cost $7,271 per year.
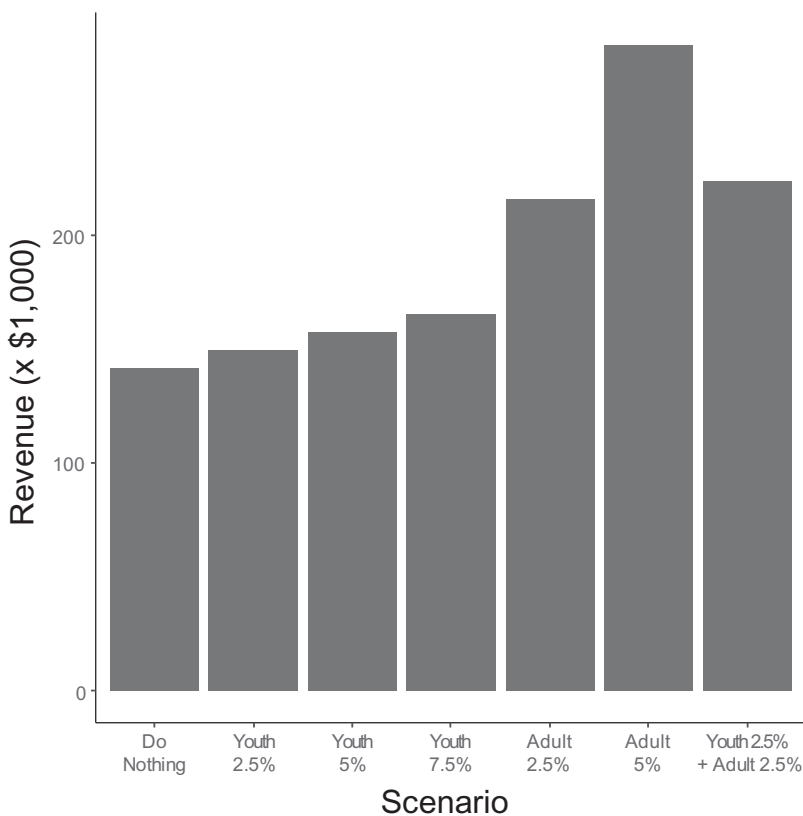

Figure 3. Predicted mean revenue generated by each management scenario over 10 years and 10,000 model realizations. The management actions were simulated using a 4-stage matrix population model with youth, potential hunting license holder, annual license holder, and lifetime license holder stages. Management scenarios consisted of a "do nothing" alternative, and varying levels of youth and adult outreach. Adult outreach was targeted at individuals in the potential license holder stage. Revenue is calculated as sum of lifetime and annual license sales.

Transition rates into the lifetime license holder stage were low, resulting in total sales that did not differ greatly among alternatives. The total number of new license sales over the time span ranged from an average of zero new lifetime license holders under the "do nothing" alternative to two for the 5% adult participation scenario. Lifetime license holders accounted for ~.5% of the total population under each scenario. The percentage of lifetime license holders out of all license holders remained around 9% for the "do nothing" alternative and decreased over the 10 years under the other scenarios due to the increase in annual hunting license holders. In year 10, the percentage of total hunters that held a lifetime license decreased to > 8% under the 7.5% youth outreach scenario and 4% under the 5% adult outreach scenario.

Sensitivity analyses showed that the decision was influenced by adult outreach parameters. The cost per adult participant and the recruitment rate of adult participants affected whether the adult outreach scenarios generated greater NPV relative to the 'do nothing' alternative (Figure 4). However, the decision was insensitive to youth parameters. Adult outreach resulted in greater NPV, even under the most optimistic youth scenarios (recruitment = 1, cost per youth = $10). The decision was also insensitive to the density-dependence parameter.
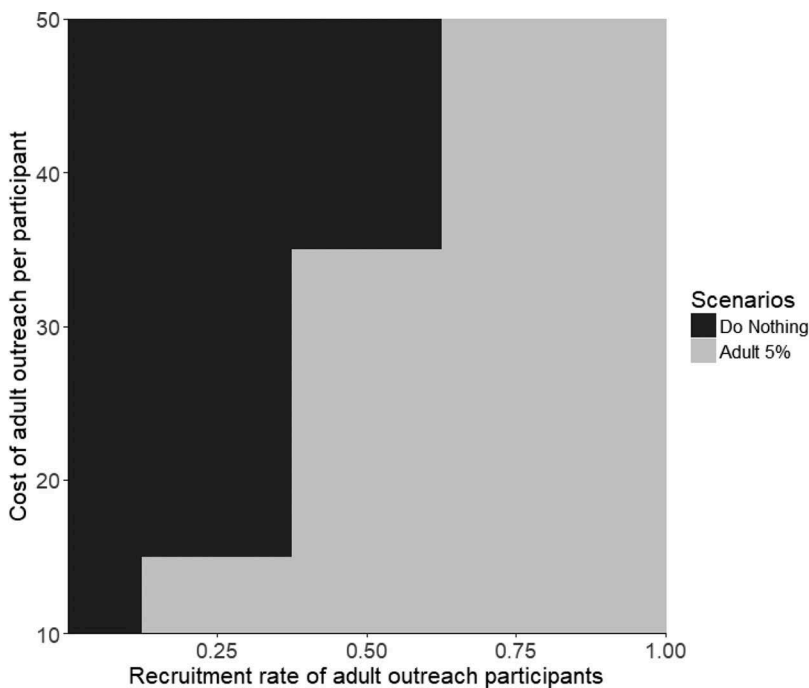

Figure 4. Two-way sensitivity analysis of adult outreach participant recruitment and cost per participant. The shade of each location on the plot represents the optimal scenario for that combination of recruitment rate (x-axis) and outreach cost (y-axis). For example, when adult recruitment is .5 and outreach costs $40 per participant, the optimal decision is the "do nothing" scenario. Although we analyzed 7 management scenarios, the only optimal decisions for the range of values we evaluated were to "do nothing" (gray shading) or implement an outreach program targeting 5% of the non-license holding adult population (black shading).

Discussion

We echo our colleagues (e.g., Heberlein, 1991; Jacobson & Decker, 2006) in voicing the need to address declines in hunters and hunter-generated conservation funds, and consider their potential to cripple state agency capacity to manage not only game species, but all wildlife. Our efforts explicitly address this issue and provide a way to aid state agencies in improving their ability to manage hunters. We built a stage-based, stochastic model of a hunter population and demonstrated its capacity within the context of a decision-making framework to evaluate state wildlife agency management actions aimed at increasing hunting license sales. Though our recruitment-focused outreach programs and results are hypothetical, our analysis is potentially useful to managers because we demonstrate the value of population modeling and decision analysis applications to managing hunter populations. Our approach is novel in that it extends methods already heavily in use in wildlife management to the management of human resource users. We directly link changes in a hunter population with economic objectives via hunting license sales. It is a strategy commonly employed to inform the management of game and endangered species, which requires explicit consideration of population dynamics alongside financial constraints. Our model is generally applicable and was designed to enable agencies to parameterize it using state license sale data (Gude et al., 2012; Schorr et al., 2014). State agencies can apply the model to predict hunting license sales, license sale revenue, and overall profit (revenue minus the cost of management with a 5% discount rate) resulting from each management scenario while incorporating temporal and parametric uncertainty. Our results highlight the relationship between population dynamics and cost, demonstrating that evaluating the scenarios based on population size (license sales) alone would imply that all the alternatives increased the number of licenses purchased, and thus were superior to the status quo scenario. However, once the cost of the management alternative was accounted for, the alternatives with youth outreach program resulted in a financial loss to the agency relative to the "no nothing" scenario. Thus, any method for informing hunter management necessitates addressing the social and economic aspects of the decision or risks leading to a suboptimal decision. SDM along with predictive modeling enables decision makers to articulate multiple objectives and subsequently evaluate management alternatives with respect to the objectives.

The results of our simulation illustrate the ability of our modeling framework to explore and elucidate complex interactions between management actions, hunters, and objectives. In our example, the results highlight important differences between adult and youth recruitment-focused outreach programs with regards to agency objectives. Our sensitivity analysis revealed that youth outreach alternatives were always inferior to adult outreach alternative. This finding agrees with recent efforts to target relatively independent and autonomous individuals, such as college students (Stayton, 2017) or other adults with nontraditional hunting backgrounds (Responsive Management, 2011). Youth outreach programs are further limited by an inherent lag time between a youth's participation in a hunter program and the age at which they are required to purchase a hunting license. Conversely, the cost and recruitment rate of adult outreach participants determined if adult outreach alternatives outperformed the "do nothing" scenario. These results demonstrate, that while our population parameters were empirically grounded, research is needed to better estimate the cost of management alternatives and their

subsequent changes to hunter demographic rates. Such information will benefit wildlife agencies interested in applying the model to their own hunter populations by improving scenario predictions and general understanding of hunter dynamics in their respective states.

The efficacy of our approach will largely rely on the ability of state agencies to clearly define objectives, and we demonstrate how this can be achieved within the SDM framework. The process requires stakeholder participation, a clearly defined problem statement, and fundamental objectives, and uses those objectives to generate potential management actions. Alternatively, an action-focused decision process can reduce the scope of potential alternatives and potentially lead to a suboptimal decision or a decision that does not address the true issue or objectives (Hammond, Keeney, & Raiffa, 1999). The problem and objectives drive the development of the suite of alternatives, and subsequently, the modeling effort (or other mechanism) for evaluating the alternatives. In our case, we clearly defined the management objective as maximizing license sale profit. This served our problem statement by directly addressing state agency funding concerns. Any changes to the problem statement and/or objectives could have led to a very different suite of management actions and model for evaluating the actions. For example, if one of our objectives had been to include some level of youth hunter outreach (as mandated by many state natural resource agencies), we would have eliminated the adult-only alternatives and included additional youth outreach alternatives. Thus, while our population model is broadly applicable, we anticipate it will be advantageous for state agencies to undergo their own decision-making process to identify their unique objectives and develop their own suite of alternatives.

The potential applications and extensions of our modeling framework are vast. Additional stages could be added to our population matrix to more accurately describe hunters, such as stages representing sex (Gude et al., 2012; Heberlein, Serup, & Ericsson, 2008), lapsed hunters (Southwick Associates, 2015), age or birth cohort (Schorr et al., 2014; Winkler & Warnke, 2013), or hunter typology (Andersen, Wam, Mysterud, & Kaltenborn, 2014; Kellert, 1978). While we focused on increasing recruitment through outreach programs, the addition of a stage representing lapsed hunters would allow for the evaluation of management actions aimed at reducing churn rates. Another possible extension could be to explore the influence of game management on hunter dynamics by linking a game population (e.g., deer, turkey) model to our hunter population model. The addition of stages or a game species population model would require the estimation of a greater number of parameters, but would expand the suite of management actions that could be evaluated to influence hunters. We also believe that our framework could easily be extended to anglers, target shooters, or other natural resource users. Anglers in particular, being consumptive users of natural resources and purchasers of licenses, pose similar issues with regards to management and value to conservation (Quintana, 2015). Our approach would fit well within current efforts to manage recreational fisheries as social-ecological systems (Arlinghaus et al., 2017).

An important limitation of our model and approach is the lack of data available to link potential hunter management actions to hunter dynamics. Human dimension surveys of hunters are common, but are typically descriptive, and may provide biased estimates of the impact of alternative system states on respondent behavior (Stedman et al., 2004). Still, we anticipate that adding in questions or conducting panel studies to address functional

relationships between management actions and hunter population dynamics can improve predictive models used to evaluate multiple management actions (e.g., discrete choice experiments conducted to inform waterfowl management; Humburg et al., 2018) . Models like the one we presented here, with hypothesized relationships and components, can also help to identify research needs. This can in turn help researchers frame survey questions to empirically estimate relationships and reduce uncertainties that were identified as key impediments to decision-making. Alternately, increasing our understanding of hunter population dynamics and structural uncertainty in our model could be addressed within a Bayesian framework in which multiple hypotheses, represented by different models, could be evaluated over time to determine the relative support for each hypothesis given empirical evidence. Such an approach could be employed within an adaptive management framework, in which explicit and iterative evaluation of management actions and post-decision data are used to inform subsequent decisions (Williams, 2011). Hunter management is an excellent candidate for adaptive management: population data are collected annually that can be used to reduce model uncertainty, and there are inherent iterative management decisions affecting the hunter population. Thus, although we have identified key areas lacking data, there are many accessible ways to reduce uncertainty.

Ultimately, we hope that our modeling framework will help managers make better decisions concerning hunters, hunter-generated conservation dollars, and other consumptive natural resource users. We provide a tool to help address the question "is the current user-pay model of wildlife conservation sustainable?" The answer may in fact be that it is not. State agency actions may be insufficient to attract individuals from nontraditional hunting background (Quartuch et al., 2017), or counter factors driving trends in hunter participation (e.g., increases in urbanization and virtual entertainment; Robison & Ridenour, 2012), and consequently do little to bolster agency budgets. We further acknowledge the fact that our model does not address the question of whether or not the current consumptive user-pay system is reasonable given the small proportion of the total population that pays for state conservation relative to nonconsumptive users. Mechanisms to garner financial support from other resource user groups, such as hikers and wildlife viewers, are lacking (Anderson & Loomis, 2006; Hamilton, 1992), despite the fact that these nonconsumptive users far outnumber hunters and anglers (*National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*, 2011). The skewed balance may cause repercussions when state agencies allocate funds supporting recreational activities (Nie, 2004). Regardless of these larger concerns, our approach can help state agencies address their budgetary concerns and capacity to continue managing wildlife resources.

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