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Peter OTTO
School of Management, Union Graduate College, ottop@union.edu

William SIEMER
Department Natural Resources, Cornell University, wfs1@cornell.edu

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Learning from cognitive feedback mapping and simulation: A group modeling intervention

Peter OTTO* & William SIEMER**

*Associate Professor, School of Management, Union Graduate College
**Research Associate, Department Natural Resources, Cornell University

ABSTRACT

This article extends previously reported work on group model building (GMB) with client groups by demonstrating specific techniques used to implement the GMB approach with public sector professionals. Wildlife agencies are just beginning to use structured decision making tools and rigorous application case studies are lacking. We address that need by describing and critiquing a GMB intervention that facilitated organizational learning and intergroup communication. This case illustrates how cognitive feedback mapping and computer simulation can: (1) help natural resource managers challenge their assumptions about coupled human-natural systems; and (2) critically reflect upon the efficacy of their management policies.

Key-words: Group model building, Decision making, Cognitive feedback mapping, Simulation.

RÉSUMÉ

Cet article est le prolongement de travaux antérieurs portant sur la modélisation de groupes (group model building: GMB) avec des groupes de clients et présente des techniques spécifiques utilisées pour appliquer l'approche de la modélisation de groupes auprès des professionnels du secteur public. Les organismes de la faune sauvage commencent tout juste à utiliser des outils décisionnels structurés et les études de cas rigoureuses font défaut. Nous répondons à ce besoin en décrivant et analysant une intervention basée sur la modélisation de groupes qui a facilité l'apprentissage organisationnel et la communication entre les groupes. Ce cas illustre de quelle manière la cartographie du feedback cognitif et la simulation informatique peuvent permettre aux gestionnaires des ressources naturelles de : (1) remettre en question leurs hypothèses concernant les systèmes couplés humains et naturels et (2) réfléchir à l'efficacité de leurs politiques en matière de gestion.

Mots-clés : Modélisation de groupes, Prise de décisions, Cartographie du feedback cognitif, Simulation.

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INTRODUCTION

Management of wildlife and other natural resources takes place within ecological and social systems that are complex, dynamic, and nonlinear (Holling *et al.*, 1998). To solve problems in this environment, organizations can use decision-support or management information systems to support managers in making well informed decisions. In situations where such systems are not available or the decision environment is too complex, managers may use simple analysis and modeling tools or rely on heuristics. Yet, even in situations where information systems are available, some facets of the management system may be unrecognized or poorly understood.

Psychological research shows that people tend to perform poorly when trying to predict the behavior of systems that are complex and nonlinear (Kahneman *et al.*, 1982). Natural resource managers need tools for inquiry that can reduce uncertainties associated with public policy decisions that are made in a politically-contentious decision-making context. Those managers can systematically address decision-making uncertainties by treating management interventions as experimental trials of competing mental models. Management experiments are advocated by proponents of adaptive resource management (Holling, 1978; Lancia *et al.*, 1996). However, such experiments are rarely implemented by governmental agencies because they are time and resource-intensive, difficult to administer and control, and politically risky.

Computer-based system modeling offers natural resource managers an alternative tool for decision support inquiry. A growing body of research evidence from cognitive science suggests that cognitive feedback can be used to enhance the quality of decision processes as well as decision outcomes (cf. Balzer *et al.*, 1989; Paich and Sterman, 1993; Sengupta and Abdel-Hamid, 1993). Model-driven inquiry can provide cognitive feedback, helping decision makers comprehend the dynamics of a problem and the potential shortcomings of existing or potential management actions. Modeling thus holds the potential to reduce a governmental organization's risk of propagating or perpetuating flawed decisions (Kleinmuntz and Thomas, 1987).

This article extends previously reported work on group model building (GMB) with client groups by demonstrating specific techniques used to implement the GMB approach with public sector professionals. Wildlife agencies generally lag decades behind the private sector in adoption of management practices. Wildlife agencies are just beginning to experiment with structured decision making (SDM) tools; use of such tools remains uncommon and the absence of rigorous application case studies in the literature is impeding dissemination and adoption of SDM practices. Natural resource agencies need examples of SDM application under conditions of actual practice to evaluate the degree to which specific SDM techniques are practical within their organizational constraints. This paper addresses the urgent need for application case studies, by describing and critiquing a GMB intervention that facilitated organizational learning and intergroup communication.

We describe how a team of engaged scholars and wildlife managers used systems thinking techniques to improve cognitive feedback about a complex management problem. Richmond (2001) defined systems thinking as a small set of skills that help people construct better mental mo-

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dels, simulate them more reliably, and communicate them more effectively. Systems thinking has been recognized as an important practice for natural resource agencies striving to apply adaptive resource management (Holling, 1978; Riley *et al.*, 2003). Riley *et al.* (2003) argue that a systems approach to making wildlife management policy decisions is advantageous because it offers: (1) better structure to guide and communicate thinking (Walters, 1986); (2) increased decision-making capacity (Forrester, 1968); and (3) increased rates of learning (Senge and Sterman, 1994).

Having an explicit vision or mental model of the system one is striving to manage is a key part of adaptive resource management (Lee, 1999:5). Wildlife management stakeholders seldom have a common understanding of ecosystems or an understanding that can be communicated in a common language. Both conditions make communication difficult. Modeling, especially when done in a group setting, is expected to help organize and communicate the complexity of management systems to managers and stakeholders (Andersen *et al.*, 1997; Bosch *et al.*, 2003, van den Belt, 2004; Vennix, 1999). Vennix *et al.* (1997:103) state that, "Model building is now increasingly seen as a method to structure debate and to create a learning environment in which assumptions and strategies can be surfaced and tested."

Information management theory leads one to expect benefits to accrue to organizations that use systems modeling. Explicit systems models are thought to facilitate organizational learning (Richmond 2001:33; Vennix *et al.*, 1997) because they capture institutional knowledge and make it available for critique and continuous improvement. Models should be useful to managers as they consider the potential effects of proposed management interventions and policies. Modeling projects also hold the potential to clarify areas where additional research is most likely to help managers improve their understanding of system behavior. Thus, modeling projects can provide input useful in setting research priorities within an organization. Despite these potential benefits, however, modeling and simulation remain infrequently used tools in natural resource management generally and wildlife management specifically. Little published work is available to gauge the utility of applied modeling projects. Paucity of case study examples may be an important impediment to dissemination of systems modeling as a process innovation. Case research is needed to clarify how natural resource agencies can effectively use simulation as a tool for inquiry.

The objective of this paper is to illustrate how a system dynamics approach can be used to facilitate learning and communication by a team of natural resource managers. The problem dimension for this study was twofold. First, the main challenge for this project was to provide credible evidence to senior management about the ability of certain conservation policies to achieve management goals. Second, it became necessary to find a way to communicate the essence of a simulation model to audiences who were not involved in the process of constructing the underling model. To address the former we adopted a modeling-simulation package. This was done so as to make the mental model of the decision-maker explicit and to help conceptualize a dynamic description of the problem system. Flow diagrams in System Dynamics offer a potential tool for communication within management teams. The process of constructing flow diagrams should elicit manager's perceptions about how a system operates (Hall, 1976). In theory, integrating manager's perceptions

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into flow diagram structure should increase manager's confidence in the structure and behavior of subsequent quantitative models.

2. PROJECT DESCRIPTION

The Bureau of Wildlife in the New York State Department of Environmental Conservation (DEC) is responsible for black bear (*Ursus americanus*) management in New York State. Black bears occur throughout New York State, with primary populations inhabiting three core ranges. DEC and other wildlife agencies in the northeastern United States reported an increased level of public complaints about problems with black bears in recent years (IAFWA 2004). Complaints to wildlife agencies serve as an indicator that people are experiencing a range of negative economic, psychological, and other effects as a result of interactions with black bears. Of particular concern in New York State is the increasing level of complaints about problem interactions in residential areas (Schusler and Siemer, 2004). Responding to bear-related problems in residential areas is costly (IAFWA 2004). It puts a strain on the small staffs of wildlife agencies and reduces the level of funding available for other management activities. Wildlife Managers also worry that negative interactions with bears may lower tolerance for bears, devalue black bears to pest status in the eyes of wildlife management stakeholders, and thus reduce public support for black bear conservation.

In 2004, we began working with a team of 10 wildlife managers to support system conceptualization, model formulation, and management response to an increase in negative human-black bear interactions in residential areas of New York State. This specific project was part of a larger effort to inform decisions within a new bear management plan (NYSDEC 2003). Our work led to production of a system dynamics model, which served to articulate the client teams' understanding of the complex interactions occurring between community residents, wildlife agencies, hunters, and black bears. The intervention culminated in production of an interface which overlays the model and allows managers and stakeholders to easily run the model to conduct management policy simulations.

Our involvement in this project contained elements of action research (McTaggart 1991, Reason and Bradbury 2001) and can be described as public scholarship (Peters *et al.*, 2005, 2007). Peters (2007:21) speaks about public scholars as "scholars who are more than responsive experts and detached social critics, but also proactive educators, citizens, and cultural workers who participate in and sometimes even organize public work." Our work was embedded in a body of public scholarship conducted by the Human Dimensions Research Unit (HDRU) (for a detailed account of that work, see Peters *et al.*, 2003). For more than two decades, HDRU scholars have facilitated collaborative research where wildlife professionals are viewed as partners in the research projects. We viewed the modeling project as another opportunity to engage as adult educators, work with wildlife professionals to organize public work, and to promote learning from scholarship about that public work.

2.1. Expectations of the project

After a set of two workshops with the project team and independent working sessions by the authors, we defined the following policy (or management action) questions to answer through a system dynamics modeling process.

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I. How would changes in (1) hunting opportunity (*i.e.*, amount of land open to hunting, season dates, season length), (2) agency effort devoted to prevention education (i.e., agency resources expended on information/education actions), and (3) agency staff capacity to respond to bear-related problems (with on-site technical assistance to residents) influence the frequency and severity of human-bear interactions in residential areas?

II. Are there points within the system creating residential problems with bears where managers could reduce the frequency or severity of human-bear interactions in residential areas through novel or innovative management actions?

These are practical management questions that may appear simple at first glance. However, each is embedded in a complex set of social and ecological relationships containing uncertainty, unrecognized parameters, and nonlinear feedback structures. The project team viewed the group model building intervention as a means to understand (and later communicate with management stakeholders about) the dynamic complexity of managing a subset of negative human-bear interactions. In addition to answering the management policy questions outlined above, the objectives of the project were to: (1) examine wildlife managers' mental models of how complaints about residential problems with black bears are generated; (2) articulate wildlife managers' assumptions about how bear population, housing density, availability of human food sources, and other key variables influence the rate of complaints about residential problems with bears, tolerance for bears, and attitudes towards bears; and (3) identify priorities for additional research (*i.e.*, identify the most important variables in the system which managers know the least about). Achieving these objectives was important to the project team because doing so would enable the team to implement subsequent steps in a cycle of adaptive impact management (Riley *et al.*, 2003).

3. METHODOLOGY

The main objective of the GMB project was to build a system dynamics model that represents the dynamic nature of a coupled social-ecological system. A differential-equation based simulation method, system dynamics is based on the fundamental tenet that the structure of causal relationships among variables in a system gives rise to its dynamics (Sterman, 2000).

As the modeling-simulation package adopted for this study, it offers a number of advantages over other modeling approaches. First, it enables the researcher to maintain a one-to-one correspondence between his verbal description of the real world system of cause and effect and the flow diagram representing this causal chain, and between his flow diagram and the set of equations in the computer program to simulate this model of causality. Second, the flow diagram provides an excellent vehicle for communicating with managers in various parts of the system in order to solicit their perceptions of how the system works. As such, the model was designed to test different wildlife management policies and to communicate about the decision environment with stakeholders. The iterative nature of conceptualizing a system dynamics model using cognitive feedback maps should help the management team to understand interactions among various factors which influence systems behavior.

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It is never possible to capture all the dynamics of a problem system in one model (Little, 1984), and adding detail complexity will not necessarily build client confidence in a model. Rather, a management team is expected to gain confidence in a model through the iterative process of making their decision environment explicit.

As Zuboff (1988) concluded, "behind every method is a belief." Our belief is that system dynamics is well suited not only to theory development but also to understanding complex behavior associated with strategy setting. Our belief is based upon the following assumptions: (1) time is an important element in constructing a conceptual framework to capture the interactions as a system responds to some agency intervention; (2) while longitudinal process models employed in research often provide a limited (linear) perspective on time (Abbot, 1995), a non-linear method such as system dynamics consists of multiple measurements of both independent and dependent variables and graphs the resulting data over time; (3) predictions made using a non linear modeling approach are more qualitative than the predictions made using traditional approaches (Svyantek and Brown, 2000); (4) an actor's interpretation of an action and its effect is part of a larger dynamic context (Sterman, 1989); (5) system dynamics models have long been associated with the notion that complex systems are counterintuitive – that the behavior of a complex system is often different from what one expects (Forrester 1961).

4. THE MODEL BUILDING PROCESS

Richardson and Pugh (1981) define seven stages in building a system dynamics model: problem identification and definition, system conceptualization, model formulation, analysis of model behavior, model evaluation, policy analysis, and model use or implementation. The system dynamics literature describes several methods of completing these stages in a group model building intervention (*cf.* Richardson and Pugh, 1981; Roberts *et al.*, 1983; Vennix, 1994). We elected to use the "standard method" (Hines, 2001) for our project. The "standard method" refers to a framework of steps to identify key variables, reference modes to formulate a dynamic hypothesis and finally to conceptualize a simulation model. The idea behind the standard method is not to think directly towards a solution at the beginning of the modeling intervention, but to gain knowledge and insights from each individual phase in the project together with the client (Otto and Struben, 2003). Besides the iterative nature of the model-building process, Hines' "standard method" specifies steps that a system dynamics modeler should consider in a consulting environment, especially during the early phases of model building. For example, to aid in problem definition, the standard method relies on developing a reference mode to express a "hope" and "fear" scenario. To aid in system conceptualization and model formulation, the standard method relies on discussions with the client to identify key variables in the problem system, and later, to complete in-depth analysis of each causal feedback loop in the system. Otto and Strueben (2004) employed the standard method to help a client examine policies to revitalize the fishing industry in Gloucester, Massachusetts. We applied the standard method driven by positive experience gained while using that approach in the Gloucester project.

In addition to using a series of iterative activities to elicit knowledge and conceptualize a model, the standard method specifies steps that a system dynamics modeler

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should consider in a comprehensive model-building initiative. For example, it emphasizes the importance of identifying key variables, which usually involves in-depth discussion with the client, a reference mode to express a "hope" and "fear" scenario, and in-depth analysis of important feedback loops in the system.

Our project included a set of on-line activities (i.e., 4 workshops with the project team) and off-line activities (*i.e.*, the modeling team met many times and worked independently on model development), completed intermittently over an 18-month period (February 2004 – July 2005). Development of the model interface was completed between fall 2005 and summer 2006 (the interface was completed through an iterative process of development, interactive sessions with a 3-member subgroup of the modeling team, and pilot test sessions with wildlife management professionals). In the following sections we describe the steps undertaken and insights gained from our modeling process.

4.1. Cognitive feedback mapping

The first part of the project involved qualitative modeling, also called systems thinking (Senge and Sterman, 1994), that goes through the process of formalizing and analyzing feedback loops for each management policy. Although formal system dynamics models are mathematical representations of problems and policy alternatives, much of the information available to the modeler is not numerical in nature, but qualitative (Luna-Reyes and Andersen, 2003; Forrester, 1994). The practice of qualitative work in system dynamics has been developed in many studies (Wolstenholme and Coyle, 1983; Coyle, 1983; Luna-Reyes and Anderson, 2003). Qualitative system description improves system understanding even where quantification is impossible.

After synthesizing information and knowledge elicited from the team of wildlife managers, the modelers constructed the first causal feedback map (Figure 1). We used the causal loop diagram to discuss the model boundaries and scope of the project with the project team as well as with wildlife experts from the Department of Natural Resources at Cornell University. After a few iterations, the project team agreed that the causal feedback map reflected their understanding of how the variables are interconnected. We also verified that the map was consistent with the structure of the real systems depicted. Structural verification was realized comparing the map's assumptions to descriptions of decision-making and organizational relationships that emerged from workshops and our discussions with experts in the field.

In our workshops with the project team we unfolded the map loop by loop, rather than showing the entire map as seen in Figure 1. The advantage of this layered approach was that we were able to capture individual loops and discuss the meaning and implications of balancing vis-à-vis reinforcing loops.

The "+" or "–" sign at the head of each arrow shown in Figure 1 indicates the nature of the relationship between each pair of variables. A plus sign means the two variables tend to move in the same direction. A minus sign means the two variables move in opposite directions.

We found that the cognitive feedback map helped the managers involved to better understand the task structure, their own cognitive system, and the mapping and fit between the two (*cf.* Hammond, 1965;

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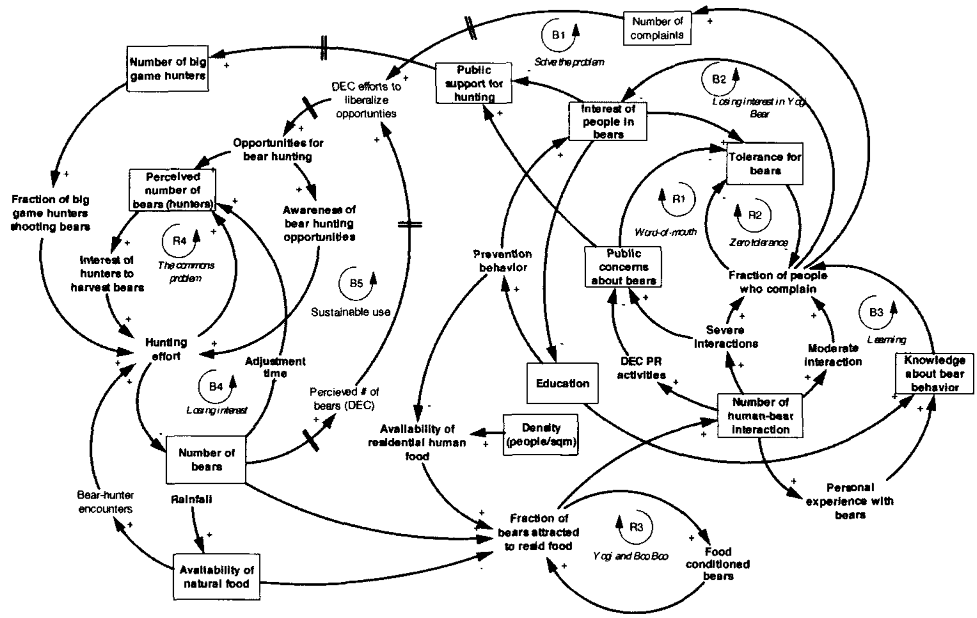

Figure 1. Causal feedback map of system under study.

Hammond and Summers, 1972). Newell et al. (1989) argue that providing cognitive feedback to decision makers should help them:

- construct an appropriate model of reality;
- operate in a real-time, rich and complex environment requiring a vast amount of knowledge;
- learn from the environment and from experience by simulation, thus enhancing the ability of the decision makers to comprehend dynamic changes in the underlying assumptions, and;
- adapt quickly to changes dictated by the users as the environment changes over time.

This cognitive feedback map proved to be very useful in getting agreement among the project team about the cause and effect of complaints from human-bear interactions. Furthermore, the causal loop diagram also improved the team's understanding of the complex interactions in this system. While cognitive feedback is effective in improving the quality of the decision maker's intuition and controlling their implementation (Doherty and Balzer, 1988) it does not enable testing policy implications and expected outcomes over time. With the cognitive feedback map as boundary object, we conceptualized the system dynamics model (presented in the following section), combining quantitative and qualitative aspects to simulate the dynamic interrelationships between systems elements.

4.2. Model Conceptualization

The problem under investigation is rooted in bear population changes, human behavior patterns, and residential development that go back several decades. We constructed a simulation model that gene-

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rally reflects historical data on bear take and bear-related complaints. We were trying to develop a simulation that would generate plausible behavior in terms of the frequency and amplitude of change in bear take and bear-related complaints. We were not attempting to build a simulation that would closely replicate historic data patterns or forecast precise levels of complaints in any future year.

We developed a model structure with six sectors: bears, hunters, food, bear-human interactions, knowledge/interest about bears, and DEC resources. We elected to develop the model in sectors in order to better visualize its structural components. Moreover, having individual sectors made it easier to communicate with the project team, since the individual model sectors reflected process maps we developed in workshops. However, for the purpose of this paper, we only show the two main sectors, bear population and hunters. Those interested in seeing the detailed model can download a free version (Vensim PLE) of the simulation software used to conceptualize the model (http://www.vensim.com) and contact one of the authors for a copy of the simulation model.

The high-level map, shown on Figure 2, captures the bear population sector and follows typical system dynamics-diagramming practices (Lane, 1994):

- Rectangles represent state variables, called stocks, where things (*e.g.* people, widgets, dollars, etc.) accumulate.
- Stocks increase due to inflows and decrease due to outflows. Flows are shown as "pipes" connected to the rectangle.
- Flows are controlled by valves, which look like small inverted bow ties.
- Arrows between variables show causality.

The model structure for the bear population is rather aggregated because we only use three age cohorts; cubs, sub adults, and adults. The structure omits immigration and emigration, two variables that can influence the stock labeled "total bears". However, after discussions with the project team it was decided that for the purpose of testing effects from different harvest levels, the structure as shown on Figure 2 would be sufficiently detailed.

The hunter sector, shown in Figure 3, depicts how the hunting rate is influenced by a number of variables. For example, public concerns, as a function of number of households complaining about human bear interactions, influences the level of public support to hunt bears. The bear hunting rate is determined by an awareness rate, a density function of food availability, the policy lever "DEC efforts to increase opportunities" and DEC staff perception of the number of bears. DEC does not have an actual count of the bear population in New York, which would determine the hunting rate, so we conceptualized a perceived value and a bear-hunter encounter rate. The perceived number of bears in the sector is a function of the total population, based on model estimates and perception delay. The bear-hunter encounter rate captures the density of bears based on availability of food. To capture the hunter population, we use a Bass-Type diffusion structure (Sterman, 2000). The four other sector views we omitted from this paper for space limitations are: food available to bears, human-bear interactions, knowledge/interest in bears, and DEC resources available for bear management. All sector maps and structural representation of the model were extensively discussed with the management team. We involved the team at every stage in the mo-

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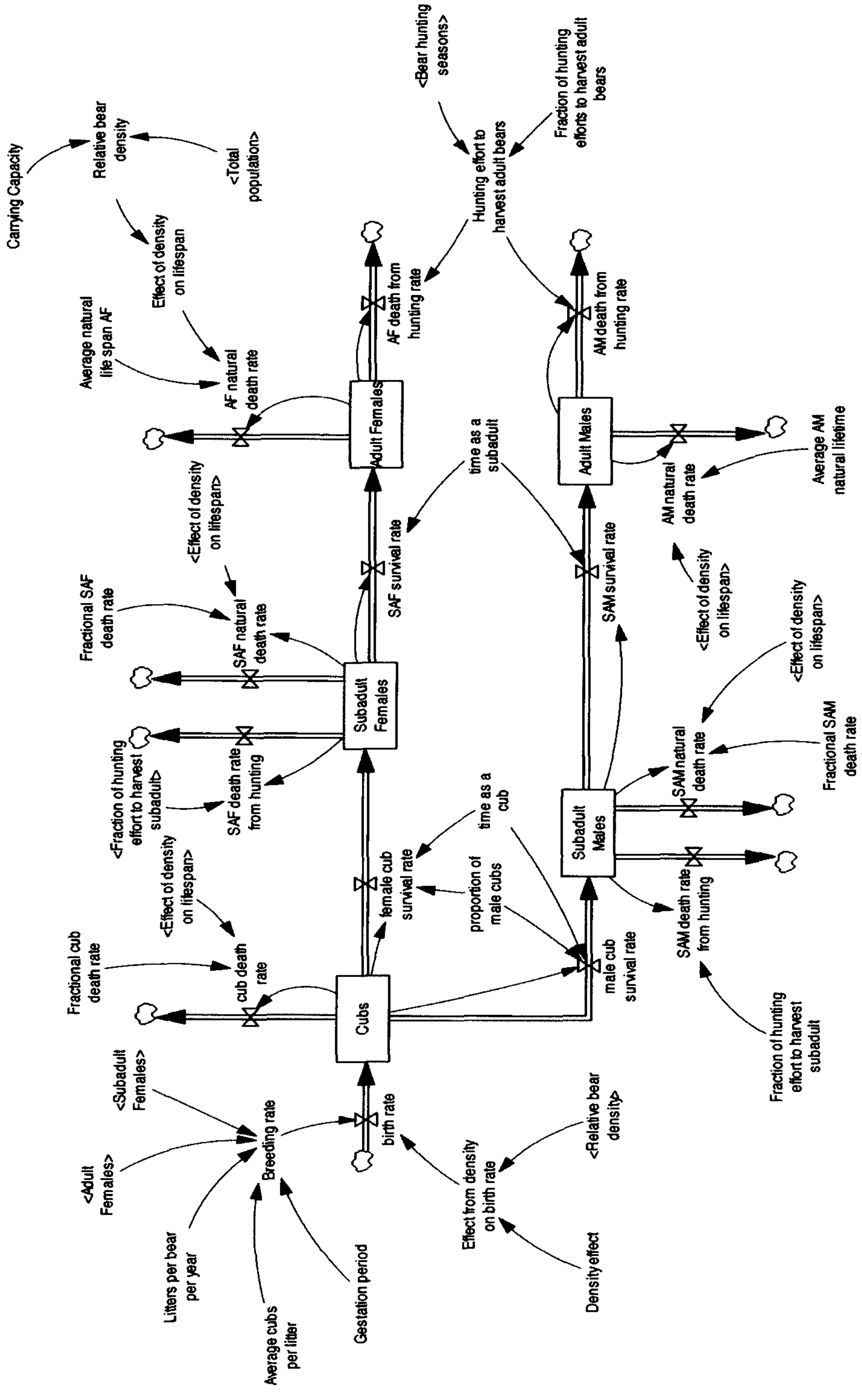

Figure 2. Model sector for bear population.

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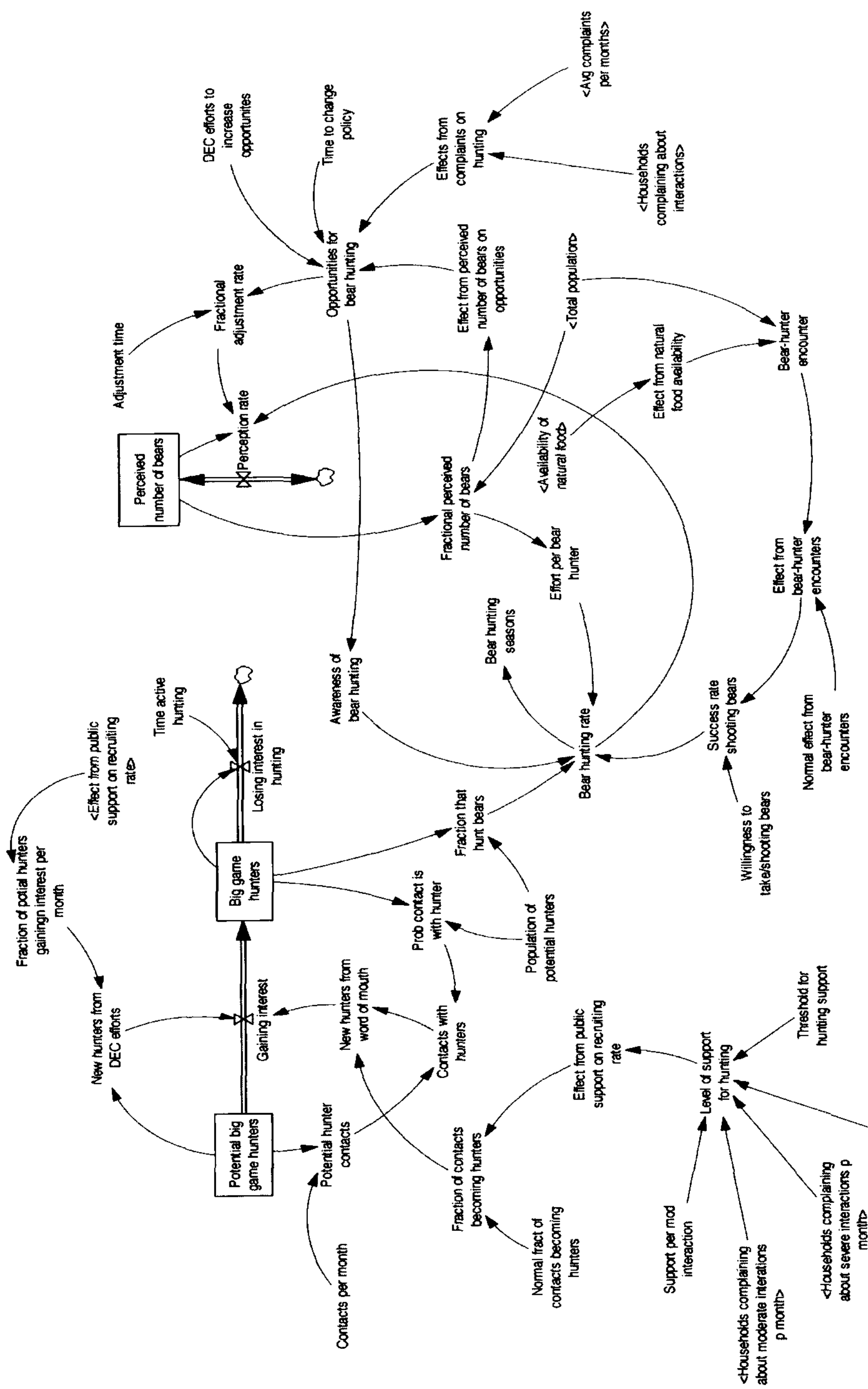

Figure 3. Model sector for hunters and hunting rate.

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del-building process, to encourage them to take ownership of the model.

4.3. Model validation

To gain confidence in the simulation model both for the researchers and the client, we rigorously performed a number of validity tests. Sterman (2000), Richardson and Pugh (1981), and Forrester (1961) have all argued that no model can ever truly be validated because every model represents a simplification of reality, not reality itself. The goal of model validation in system dynamics is to determine whether a model is appropriate for a given purpose and whether model users can have confidence in it. A large and diverse array of potential validity tests appear in the system dynamics literature. Selecting and applying a sub-set of tests best suited for one's particular situation can be a daunting challenge. Barlas (1996) proposes a narrow set of model validity tests believed to be most important. Sterman (2000) offers 12 tests, examining models on both structural and behavioral grounds. Other tests focus on collaborative model building projects that include both modelers and model users. Richardson and Pugh (1981) divide confidence-building tests into those that test for suitability and those that test for consistency. Suitability tests determine whether the model is appropriate for the problem it addresses, while consistency tests examine whether the model is consistent with the particular aspect of reality it attempts to capture. In validating our model, we performed direct structure tests (Forrester and Senge, 1980) and compared our model with generalized knowledge about the system that exists in the literature.

To perform dimensional consistency and extreme condition tests, we used VENSIM's software environment to a) ensure that unit variables were consistent and b) to see how the model responded when parameters were changed to extreme values. In order to perform parameter confirmation tests, we used real-world data provided by the management team or we searched the literature for available knowledge about the real system. For example to simulate the effect of food availability, a parameter, which influences the migration of black bears, we used historic weather data to mimic real-world behavior. For parameters for which we did not have empirical values we used a "best-guess" approximation in discussion with the client and tested the value of our assumptions using VENSIM sensitivity analysis (Monte Carlo Analysis). Finally, parameters were adjusted to replicate the time series data in Figure 4.

Figure 4 shows a historic data series over a time period of 50 years of harvest rate (Y-axis, number of bears) in comparison to model data. Surveys and other sources of quantitative data were also available to set initial values and guide model development. Other attributes, underlying hunting rate, and other policy-related parameters were identified through secondary research and in discussion with the management team. Because we had little information about the harvest policies behind the historic data and the associated amplifications, we did not attempt to align the model data to the historic data. Instead, we aimed to produce a model that could match the underlying trend in historic data. The exponential trend line suggests that the model is getting close to real-world behavior on the characteristic most important to the management team. Because most of the variables used in the model are hard to measure, calibrating against real data does not mean the model is valid for all purposes. However, the pattern

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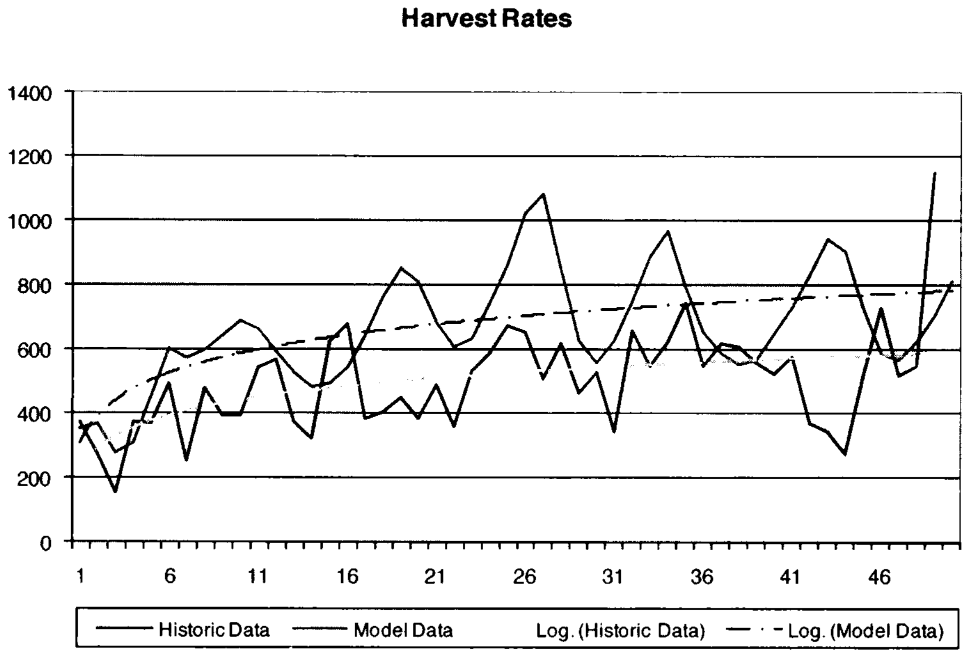

Figure 4. Model calibration.

matching shown in Figure 4 should create confidence that the model is a valid tool for inquiry about the questions facing this team of managers.

5. USING THE MODEL AS A TOOL FOR INQUIRY

In the remainder of the paper, we will discuss how the model was used by managers to test different management policies and how the modeling intervention facilitated learning within and beyond the model-building team. As noted earlier, one purpose of building the model was to help a team of DEC managers critique the value of three management actions they could take to reduce negative human-bear interactions.

DEC has the legal authority to impose a policy that would radically reduce bear numbers, which would reduce the number of negative human-bear interactions. However, such a policy must be considered in light of other management goals (*e.g.*, maintaining a sustainable bear population for future generations to enjoy). Ideally DEC was aiming for a public policy that would balance competing management goals such as maintaining a sustainable bear population while concurrently minimizing negative human-bear interactions and the negative consequences of those interactions. In addition to informing internal discussion, the team that developed the model hoped that it could inform communication with stakeholders (*e.g.* recreationists, landowners, homeowners, local communities, and nongovernmental organizations) about the effectiveness of its policies and the underlying complexities associated with reaching competing societal goals.

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5.1. Conditions for Base Run

Due to limitation of space in this article, we only present a few selected graphs to show the behavior of some key indicators in the system. However, the model is able to dynamically present all the key variables as shown in the causal feedback map in Figure 1. The graph in Figure 5 depicts the population dynamics of bears and hunting rate (bears per month) over a time of 50 years.

As noted earlier, we calibrated the model using historic data where available. The base run on Figure 5 captures the population dynamics of black bears in New York State and the hunting rate, following observations from DEC and a fragmented data series about the number of black bears in New York. The line in Figure 5 depicts sharp annual drops in bear population due to hunting mortality. We replicated seasonal hunting mortality by incorporating a pulse function that introduces higher levels of bear mortality in October, November, and December.

5.2. Policy Experiment: Problem Prevention Education

One of the policy levers the management team investigated was agency investment in problem prevention education (*i.e.*, agency resources expended on information or education actions to prevent problems with bears in residential areas). For example, in order to reduce the negative impact of human bear interaction, DEC provides information material and educational events to make people aware how to respond in case they experience a bear on their property.

In this policy experiment, we increase the amount DEC is devoting for prevention education from US$5000 per month to US$15000. The concept "knowledge about coping with bears" was conceptualized in our model as a state variable representing

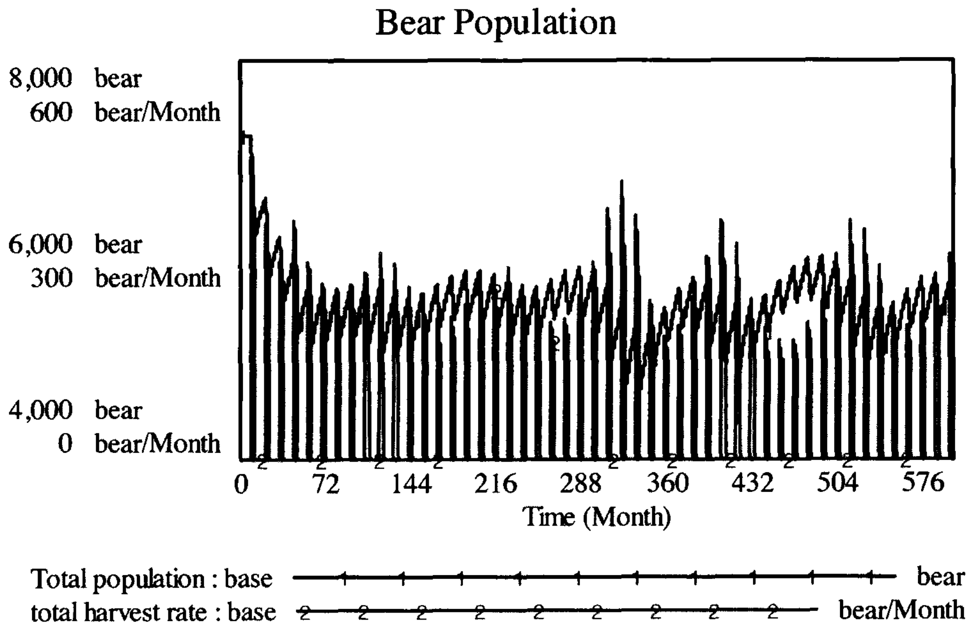

Figure 5. Harvest rate and bear population of the simulation model.

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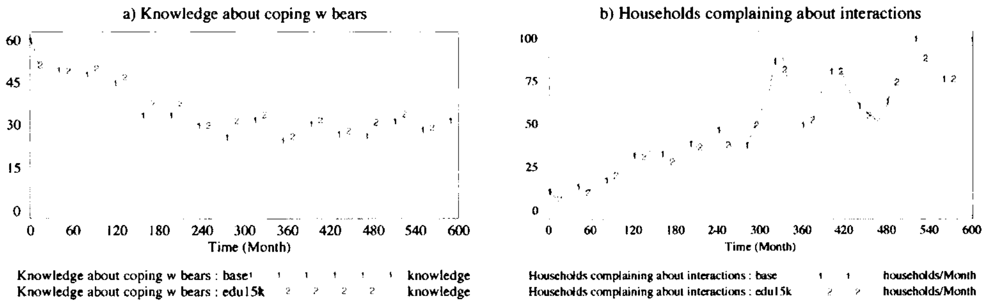

Figure 6 a&b. Simulation result prevention education.

an aggregated view combining knowledge levels and interest in bears. The initial value for this state variable was taken from survey research in southeastern New York State, which found that 59% of households knew how to keep bears away from their home (Gore, 2007). The result of this policy change is shown on Figure 6 a&b. While knowledge about coping with bears is increasing slightly and the number of households complaining about problems is decreasing in both graphs, over time increasing expenditures on prevention education only yields marginal improvement toward the management goal of reducing household complaints about bear problems. Comparing the result to the base line, this policy does not achieve its expected results. We attribute this behavior to the structural dimension in our model of how knowledge can be gained through education and learning from observing bears and lost, on the outflow side, from experiencing negative bear interactions. Human behavior change per unit effort by DEC would have to improve in order for prevention education to be an efficient management response.

5.3. Policy Experiment: Staff Resources for Problem Response

The next experiment simulated how agency staff capacity to respond to bear-related problems (with on-site technical assistance to residents) influences the frequency and severity of human-bear interactions in residential areas. DEC staff resources determine the agency's capacity to respond directly to complaints from households. Response to moderate problem interactions requires 1 hour of staff time. Response to severe interactions requires 12 hours of staff time. If staff size (number of people) is adequate to respond to complaints, collective concerns about bears do not increase. If staff size is inadequate to respond to complaints, collective concerns about problems increases, which contributes to an increase in problem complaints. The graphs in Figure 7 a&b depicts how the system responds when DEC is assigning adequate resources to cope with complaints from human bear interactions.

The policy of adding staff members results in a decrease of household complaints (see Figure 7b) and an increase in the bear population (Figure 7a). As modeled in the system, this policy removes an upper boundary for hiring additional staff members when the number of household complaints increases. As the number of complaints decreases so does the level of support for hunting, a variable in the model that captures how complaints amplify public support for bear hunting. Interestingly,

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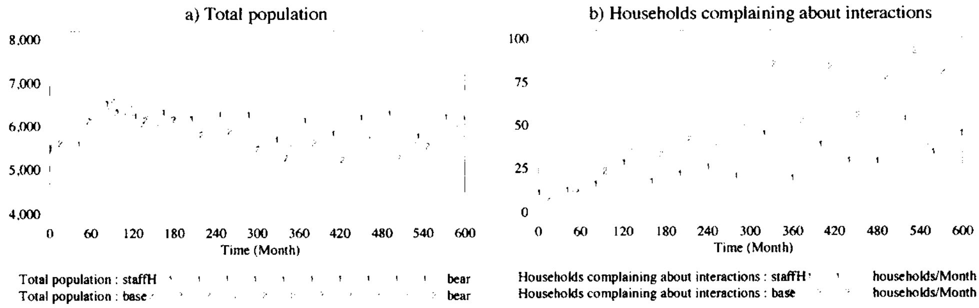

Figure 7 a&b. Simulation result DEC staff resources.

the bear population is increasing while the number of complaints is decreasing. These model results suggest that having enough staff resources helps to mitigate the negative effects of human-bear interactions in two ways. First, wildlife managers can respond to moderate a problem, which helps households to increase awareness and knowledge about bear encounters and thus improves prevention behavior. Second, having adequate resources to respond to severe human bear interactions reduces public concerns and subsequently support for more hunting pressure on bears. The real-world implication from this policy experiment is that an ideal policy response from DEC would involve careful monitoring of the number of complaints and annual weather conditions, followed by additional allocation of staff resources for direct response adequate to service increased complaint loads in some years. Alternatively, the agency could consider providing more capacity for personal service by empowering private sector agents (*e.g.*, nuisance wildlife control businesses) to respond to homeowners with a bear problem.

5.4. Policy Experiment: Changing Hunting Opportunity

Changing hunting opportunity is arguably the most controversial policy wildlife agencies offer as a response to negative human-bear interactions. The management team involved in this project uniformly expressed a belief that increasing hunting opportunity would be the most effective policy to reduce bear-related problems and problem complaints to the agency. However, wildlife managers in New York also have a mandate to maintain a viable bear population at the state-wide level. An unregulated hunting system that included the possibility of extirpating bears from the state is not legal or desirable in New York. Thus we incorporated a balancing loop in our model to replicate the mandate for a viable bear population (i.e., if hunting rate reaches a critical level [modeled as the ratio between the number of perceived bears and bear population] the hunting rate in the system levels off). In this experiment, we increased the policy parameter "opportunity for hunting" from 0.6 to 1 (the scale is from 0 [no hunting at all] to 1 [maximum hunting]).

As a result of increasing hunting opportunity, the bear population is reduced to a level which reflects the mandate for a viable population as shown in Figure 8a. In Figure 8b, we compare the hunting policy (Curve 3) with the base line (Curve 2) and the result from the resource policy of providing adequate resources to cope with household

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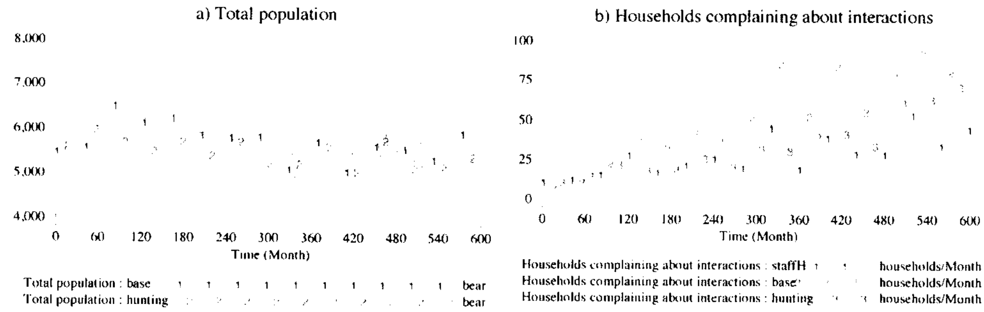

Figure 8 a&b. Simulation result for increased hunting.

complaints (Curve 1). Modeling results suggested that increasing hunting opportunity reduces complaints about bear-related problems, but even greater reductions in complaints occur when managers implement a policy of increasing resources for staff to respond directly to bear-related problems. This prediction is remarkable because it is counterintuitive to the management team's preconceived notion that hunting alone may have the highest leverage to reduce the number of complaints from human-bear interactions.

6. DISCUSSION

This case demonstrates how cognitive feedback mapping and computer simulation can: (1) help natural resource managers challenge their assumptions about coupled human-natural systems; and (2) critically reflect upon the efficacy of their management policies. Demonstrating that such outcomes are possible within the constraints faced by state wildlife agencies will encourage state agencies to additional trial of decision support tools like group model building.

The above discussion clearly illustrates how a simulation model can be linked to normative decision making as well as serve as a tool to gain insights into policy levers to manage a complex ecological system. As such, our case demonstrates how cognitive feedback mapping can provide a useful tool for inquiry about natural resource management issues. Data from participant observations, open-ended interviews, internal group correspondence, and secondary document analysis were used to critique this case (see Siemer, 2009). Siemer (2009) concluded that cognitive feedback mapping helped this team of natural resource managers to better understand and communicate about a complex issue. Other benefits that accrued through cognitive feedback mapping and simulation included: organizational learning, identification of information gaps (*i.e.*, research needs), and more systematic consideration of management interventions.

6.1. Organizational learning

Organizational learning is essential for organizations to understand and adapt to change. Learning occurs through synthesis of information and knowledge, articulation of that synthesis, and communication of insight across the organization. Follow-up evaluation (Siemer, 2009) provided multiple indications that organizational learning occurred as a result of systems modeling activity. A foundation for learning

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was created when participants crafted a consensus problem definition (described in Siemer and Otto, 2005) as one of the first steps in the modeling process. The causal loop diagram (CLD) developed by project facilitators and participants (Figure 1) is a graphical representation of participants' mental model of the system that generates residential problems with black bears. Modeling the problem together seemed to create a sense of participant ownership in the CLD. The CLD and background information associated with it represents the first complete articulation of the bear management system in New York State. The CLD and stock-flow model produced in this project thus provided an unprecedented level of documentation about assumptions and choices of bear managers in New York. As such, the CLD provides a tool (i.e., an institutional memory) that the sponsor agency can use in coming years to train new staff and to craft consistent messages about their management program. Having the information synthesized in a way that can be consistently communicated to other managers and stakeholders should make the bear management program more transparent and open to healthy discussion about program improvement. Articulating New York's bear management program was perhaps the most important, and certainly the most tangible, product associated with the work.

Eight of the original ten participants remained involved throughout the life of the group model building project. In a post-project survey, all eight long-term participants reported that the modeling project had value as a learning experience (Siemer, 2009). Most reported that the experience helped them gain better understanding of one another, the bear management system, and how to manage negative interactions with bears in residential areas. Seven of the eight long-term participants believed the project was useful as a way to stimulate thinking about means to achieve management objectives and as a means to clarify how bears impact people in residential areas. In the post-project debriefing sessions, participants responded unanimously that the project had increased their understanding of the problem system and the main actions their agency takes to manage the problem. They believed that the project yielded understanding about the management system and would encourage staff in their agency to approach bear management as an ongoing, dynamic process. The act of synthesizing diverse knowledge bases in the form of qualitative and quantitative models was valued by project participants, as illustrated by the interview quotes below.

> I've been particularly impressed by the amount of information captured in the model ('behind the curtains'). The simulation provides a good demo of the value of active management, with undesirable outcomes from either overly aggressive or overly conservative approaches. [Participant #6]

> ...it [the modeling work] did bring out information that we've had sitting around for awhile or that we've had out there, and we were able to relate that information. Which was nice to see, from some of the data that we've collected. [Participant #10]

6.2. Clarification of research priorities

The modeling project was useful to project participants as a means to identify important gaps in information about their problem system that should be addressed through additional research. When asked whether he found the model useful, one participant said, "It does for me what

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most models do. It tells me what I didn't know and tells me where to start looking for answers about the questions I can't answer." Quantitative modeling was necessary, in this participant's mind, to identify such information gaps, because qualitative modeling does not challenge assumptions and does not force wildlife managers to carefully articulate their beliefs. In this case, modeling identified a need for additional research on: factors that affect concern about human-bear interactions; and, the relationship between risk perception, risk communication, and problem-prevention behavior by residents who experience bear-related problems. The project agency went on to sponsor additional research to address some of those information gaps (Siemer *et al.*, 2009).

6.3. Systematic consideration of potential management interventions

By incorporating a modeling aspect into their work, wildlife managers employed a more systematic process for considering their intervention alternatives. The suite of management interventions offered by the agency did not change markedly after the project, but the process they used to guide their program had become more systematic and transparent (Siemer, 2009). Improving the **processes** by which wildlife managers consider information in decision making represented a positive and important advance in a bureaucratic system that is resistant to innovation, change, and strategic planning. Decision-making literature assures us that a better process for decision making generally improves the decision maker's odds of achieving better outcomes (Hammond *et al.*, 1999).

This case illustrates how governmental agencies can use simulation to inform their understanding of the systems in which policy decisions will be implemented. Simulating implementation of competing policy options can help government agencies to reduce uncertainties and to rigorously work through policy options in reference to management goals and the likelihood that a given policy will result in goal attainment. Simulation projects like the one illustrated here need not assume that governmental agencies will or should practice a rational-comprehensive approach to making policy decisions, despite the fact that policy analysis approached through means-ends analysis has some of the earmarks of the rational-comprehensive approach. Rather, such projects should assume that using simulation as a tool for inquiry will help governmental agencies implement an improved or informed incremental approach to policy making. Simulation can be a useful tool even when we accept the tenets of bounded rationality theory (Simon, 1979) (*e.g.*, that decision makers can effectively handle only small quantities of information; that policy decisions are influenced by the individual decision makers and the organizations in which decision makers work; that decision makers are susceptible to cognitive decision traps; that organization members modify their perceptions of problems to justify their actions).

We used our model as the basis for a computer simulation that would serve as an issue education tool, and we published the simulation as part of a practitioners' guide (Siemer *et al.*, 2007) for use by wildlife professionals and nongovernmental organizations willing to take leadership roles in policy discussion. Use and evaluation of those educational resources should provide additional insight about the potential value of simulation for social learning and ef-

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fective approaches to making public policy decisions.

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Bruno BEAUFILS est maître de conférences en informatique à l'Université des Sciences et Technologies (Lille 1) et membre de l'équipe SMAC du LIFL, UMR CNRS-USTL 8022. Ses travaux portent sur la théorie des jeux computationnelle et l'intelligence artificielle dans le cadre de modélisations multi-agents.

Adresse : Université de Lille1

Mail : bruno.beaufils@lifl.fr

Olivier BRANDOUY est professeur de sciences de gestion (Finance) à l'Université Paris 1 Panthéon Sorbonne (IAE) et chercheur au GREGOR, EA 2474. Ses recherches portent sur la théorie financière, la finance computationnelle et l'asset management.

Adresse : GREGOR, Sorbonne Graduate Business

Mail : olivier.brandouy@univ-lille1.fr

Nikolaos P. EVANGELOPOULOS is a PHD Student in the School in the School of Mechanical Engineering in NTU Athens, Section of Industrial Management and Operational Research. His research interests are Business Process Modelling and Simulation and IT-enabling Technology.

Adresse : National Technical University of Athens, 15780 Zografos, Athens, Greece

Mail : nik.evang@gmail.com

Jean-Mathias HERAUD est enseignant-Chercheur en Management des Systèmes d'Information au Groupe ESC Chambéry et chercheur associé au SYSCOM, Université de Savoie. Il travaille sur le management des connaissances et l'apprentissage par simulation en utilisant l'analyse des traces informatiques.

Adresse : Groupe ESC Chambéry - 12 av. Lac d'Annecy - 73381 Le Bourget du Lac

Mail : jm.heraud@esc-chambery.fr

Dominique KREZIAK est maître de conférences en marketing à l'Institut de Management de l'Université de Savoie et chercheuse à l'IREGE. Elle travaille sur l'éco-citoyenneté et la sécurité alimentaire, ainsi que sur le lien entre comportement du consommateur et protection de l'environnement.

Adresse : IMUS - Route de Saint Cassin - BP 1104 - 73011 Chambéry

Mail : dominique.kreziak@univ-savoie.fr

Lin MA est doctorante en sciences de gestion (finance) à l'Université des Sciences et Technologies (Lille 1). Ses thèmes de recherche sont l'efficience des marchés financiers et la finance computationnelle.

Adresse : Université de Lille1

Mail : lin.ma@iae.univ-lille1.fr

Philippe MATHIEU est professeur d'informatique à l'Université des Sciences et Technologies (Lille 1) et responsable de l'équipe SMAC du LIFL, UMR CNRS-USTL 8022. Ses recherches portent sur l'intelligence artificielle, les systèmes multi-agents, et la modélisation de comportements.

Adresse : CNRS-LIFL, University of Lille 1

Mail : philippe.mathieu@lifl.fr

Hélène MICHEL est directrice de la Recherche au Groupe ESC Chambéry, Docteur en Management et chercheuse associée à l'IREGE, Université de Savoie. Elle travaille sur l'impact des technologies de l'information et de la communication sur la gestion de la relation au citoyen.

Adresse : Groupe ESC Chambéry - 12 av. Lac d'Annecy - 73381 Le Bourget du Lac

Mail : h.michel@esc-chambery.fr

Peter OTTO is associate professor at the School of Management of the Union Graduate College. He holds an MBA and a PhD in Information Science, with primary specialization in Decision Support Systems, from the University at Albany, New York. His present research focuses

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on group decision making and online communities.

Adresse : Union Graduate College, 807 Union Street, Schenectady, NY 12306

Mail : ottop@union.edu

Nikolaos A. PANAYIOTOU is a Lecturer in the School of Mechanical Engineering in NTU Athens, Section of Industrial Management and Operational Research. His academic interests are Business Process Reengineering, Business Process Improvement, Performance Measurement and IT-enabling Technology.

Adresse : National Technical University of Athens, 15780 Zografos, Athens, Greece

Mail : panayiot@central.ntua.gr

Martin SCHAFFERNICHT est professeur à la Facultad de Ciencias Empresariales de l'Université de Talca au Chili. Sa thèse sous la direction de Robert Reix s'est consacrée au sujet de l'apprentissage dans les organisations. Depuis, sa recherche porte sur la relation entre modélisation et apprentissage du point de vue de la dynamique des systèmes.

Adresse : Universidad de Talca. Avenida Lircay s/n. Chili

Mail : martin@utalca.cl

William F. SIEMER holds a PhD in Natural Resources from Cornell University. His current research focuses on processes to enhance systems thinking, learning, and decision making within natural resource management agencies.

Adresse : Cornell University, 119 Fernow Hall, Ithaca, NY 14853

Mail : wfs1@cornell.edu

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