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# DeerKBS: a knowledge-based system for white-tailed deer management

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**Abstract**

Recognizing that wildlife managers are facing many challenges (e.g. increased numbers and involvement of stakeholders) and decisions must be made on conflicting expectations and limited data, we developed a knowledge-based system for white-tailed deer management (DeerKBS) to assist wildlife managers in making informed decisions. This system employed wildlife managers' expertise and knowledge, and standardized decision-making procedures for management. A 'top down' technique was used to divide the task of deer management decision-making process into four subtasks: (1) deer population evaluation, (2) deer habitat evaluation, (3) social carrying capacity evaluation, and (4) environmental evaluation. Each subtask was represented by a decision tree, developed and tested separately. The 'top-down' technique offers the flexibility to include more information when available. DeerKBS is an effective communication tool for presenting the decision-making process to stakeholders, and an educational tool to help users understand the complexity of the management decision-making process. 

*Keywords:* DeerKBS; Knowledge-based system; *Odocoileus virginianus*; Deer management; White-tailed deer; Social carrying capacity

## 1. Introduction

Wildlife management is a blend of science and art. Many studies have emphasized the importance of scientific investigations into wildlife populations and habitats (McCullough, 1979). However, what makes wildlife management different as a practice from the discipline of wildlife science is the importance of art in management. Some argue that wildlife management is still more of an art than a science (Walker, 1998). Furthermore, stakeholders such as hunters, farmers, and environmental activists are demanding increased involvement in the wildlife management decision-making process. To make management more effective, wildlife managers need to balance relationships among relevant factors in order to address an array of complex issues.

Management decisions must be made, even with conflicting goals, scientific uncertainties, and

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incomplete/qualitative data (Ludwig et al., 1993; Ehrlich and Daily, 1993; Liu et al., 1994, 1995). It would be easier to make decisions with the aid of knowledge-based systems (KBSs) because KBSs, a branch of artificial intelligence (AI), can assimilate human knowledge and provide the reasoning necessary to make informed decisions (Duda et al., 1979; Schmoldt and Rauscher, 1996; Bremdal, 1997). Generally speaking, KBSs are computer systems that use human knowledge to solve problems that would normally require human intelligence (Edwards, 1991). KBSs differ from other AI programs in their performance, domain-specific problem-solving strategies, and their justification for conclusions. Furthermore, KBSs differ from conventional software programs in their symbolic representation, symbolic inference, and heuristic search (Hayes-Roth et al., 1983).

White-tailed deer (*Odocoileus virginianus*) are one of the most important game species in the world. Deer management is quite complicated and includes the management of the deer population, deer habitat, and people (Giles, 1978; Decker et al., 1992). As deer managers often make their decisions based on their own expertise, it is usually hard for stakeholders to understand the rationales of management decisions. On the other hand, it often takes a long time for deer managers to acquire sufficient experience to be effective. Retaining the valuable knowledge of experienced deer managers is important for management agencies to make more consistent decisions and to prevent the loss of institutional knowledge and memory. Thus, it is essential to retain management expertise as well as facilitate communication among deer managers and stakeholders.

In this study, we constructed a deer knowledge-based system (DeerKBS). Our objective was to provide a practical and standardized decision-making framework for deer management that helps users identify management issues and make informed decisions. We parameterized DeerKBS using information related to white-tailed deer management in the Upper Peninsula (UP) of Michigan, USA (Xie et al., 1999).

## 2. Methods

### *2.1. Study area*

The UP of Michigan is an area of 43,070 $km^2$ in the northern part of the midwestern United States. The deer population in the UP has increased dramatically in the past several decades (Winterstein et al., 1995). The increase in the deer population has provided an exceptional opportunity for deer hunters, but has also generated a series of ecological and socioeconomic consequences, including agricultural crop damage, tree regeneration problems and traffic accidents (Xie, 1999). As a result, deer managers in the UP, like those in many other parts of the United States, are faced with an increasing challenge of meeting the needs of multiple stakeholders (e.g. deer hunters, farmers, and other interest groups).

The Michigan Department of Natural Resources (MDNR) is the lead agency responsible for establishing deer harvest recommendations, which requires information regarding deer habitat, deer numbers, and stakeholders. Deer habitat was evaluated through field surveys and remote sensing imagery analysis (Xie, 1999). Deer population data were obtained through several methods such as: pellet group surveys, sampling licensed hunters via mail surveys, reported kills through deer hunters at voluntary check stations during the hunting seasons, deer-vehicle accidents compiled by the Michigan State Police, summer deer observation surveys, and deer population models (Xie et al., 1999). Socioeconomic data such as attitudes of stakeholders toward deer management were collected through interviews and mail/phone surveys (e.g. Minnis, 1996). Much of the data is qualitative. Although some of these data are quantitative, they lack a high degree of precision. Furthermore, deer population indices such as reported kills and deer-vehicle accidents do not provide absolute deer numbers. These data limitations do not create a big problem as deer managers often rely on qualitative information when making management decisions. Furthermore, management decisions are frequently based on the population size relative to biological carrying capacity (BCC), social carrying capacity

(SCC), and the trends of deer population changes, rather than the absolute number of deer (Hayne, 1984). What is essential, however, is a useful tool that integrates various sources of data so that management decisions can be well founded and balanced. To address this need, we developed a knowledge-based deer management decision support system.

### 2.2. System components of DeerKBS

The main components of a KBS include a knowledge base, reasoning engine, and user interface. Analogous to a database (a collection of data), a knowledge base is a collection of knowledge. There are many different ways to represent knowledge, such as rules (Shortliffe, 1976; Davis et al., 1977; McDermott, 1982), frames (Minsky, 1975), scripts (Schank and Abelson, 1977), objects (Goldberg and Robson, 1983), and networks (Quinlan, 1986). In DeerKBS, we used rule-based knowledge representation because it has some desirable properties for system development. For example, each rule represents a 'chunk' of knowledge for a specific domain (Duda and Gaschnig, 1981). The rules have the uniform structure and are grouped into modules, thus making development and maintenance easier (Schmoldt and Rauscher, 1996).

The reasoning engine is a set of reasoning methods that determine the mechanisms by which the system makes decisions based on knowledge stored in the knowledge base. Decision making or problem solving in artificial intelligence is a process of searching for a solution (a state) from a collection of solutions (a state space). Two mechanisms are involved in this process: inference and control. In DeerKBS, a decision tree search is used as inference that generates new assertions. A decision tree is a hierarchical structure with each node (a branching point in a tree) determining which lower node will be searched, and each leaf (terminal point) representing a solution. The tree structure offers a control strategy and the nodes allow for inferences (Quinlan, 1986). Both backward chaining and forward chaining are used in DeerKBS as control methods that determine how the system seeks solutions. Forward chaining is a data-driven search strategy, whereas backward chaining is a goal-driven search strategy.

The third component of KBS is the user interface, which determines how users interact with the knowledge base through the reasoning engine. In DeerKBS, a graphical user interface (GUI) is used to ease the system usage.

### 2.3. System development of DeerKBS

A traditional life cycle for software engineering follows a waterfall model (Boehm, 1976) that includes 5 major phases: specification, design, implementation, testing, and maintenance. The model requires that complete specifications and assessment criteria for each phase can be provided before system design and implementation so that the overall development remains linear. A knowledge engineering life cycle usually follows a spiral model, which has similar components to the waterfall model but is characterized by iterative design and prototyping. One of the widely used spiral models in KBSs is the life cycle model proposed by Buchanan et al. (1983) that includes five iterative steps: identification, conceptualization, formalization, implementation, and testing. In Buchanan's model (1983), knowledge acquisition is an ongoing central activity across different development stages. The system development is a cyclic process. A variant of this model (Awad, 1996), which focuses on structured tasks, includes the following stages: problem identification, selection of KBS tools, knowledge representation, implementation, and operation and maintenance.

The development of DeerKBS follows the above-mentioned phases. The first phase is domain problem identification that leads to problem definition. Once the problem is defined, a KBS tool is determined based on system requirements. Then the concern of the development focuses on knowledge acquisition, prototyping, and validation. Following this phase are system implementation, operation, and maintenance.

#### 2.3.1. Domain problem definition

Problem defining is the process that identifies the scope, requirements, and objectives of the problem-solving system. Deer managers in Michigan often establish deer management objectives at hierarchical management levels (deer management unit (DMU), districts, regions, and state) based on their assessments of deer population, habitat status, and stakeholders' attitudes. The long-range objective in Michigan is a fall population of 1.3 million deer, 35% of which should be antlered bucks (MDNR, 1993). Each year, deer managers recommend having more, fewer or the same number of deer for each management level compared with that of the previous years. These recommendations are based on the following considerations and assessments (Langenau, 1994; Ozoga et al., 1994):

1. Deer status: including deer population density and the percentage of antlered bucks in the population.
2. Habitat status: including habitat quantity and quality.
3. Social carrying capacity (SCC): deer population levels acceptable to stakeholders such as deer hunters, farmers, and other interest groups (Minnis, 1996).
4. Environmental conditions: winter conditions measured by winter severity index (Verme, 1968).

DeerKBS divides the whole task of decision-making for deer management into a few subtasks. Each subtask can be further divided. If DeerKBS is viewed as an intelligent agent, an application performing some tasks for the user (Prerau et al., 1997), then each subtask can be assigned to a subagent that is an expert who makes his or her own decisions in a specific field. For example, the subagent for deer population management can be an expert or a panel of experts who specialize in deer population evaluation and decide whether the population size is satisfactory, too high, or too low. The outcomes of DeerKBS can be a suite of recommendations for deer harvesting.

*2.3.2. Selection of KBS tool: XpertRule KBS*

XpertRule KBS (Attar Software Ltd, 1996) was chosen for DeerKBS development. XpertRule KBS is a shell tool for the graphical development and maintenance of knowledge-based applications under the Microsoft Windows® environment. An XpertRule application is constructed graphically as a hierarchy of chained tasks. A task can consist of a decision tree representing a flow chart controlling procedures, dialogs, reports or other tasks.

*2.3.3. Knowledge representation*

Knowledge engineering is the process that centers on transforming expertise to a knowledge base. This process can be further divided into three steps: knowledge structuring, knowledge acquisition, and knowledge validation.

*2.3.3.1. Knowledge structuring*. Knowledge structuring transfers the problem-solving conceptual model into a structural hierarchy of decision-making tasks that relate management alternatives with ecological and socioeconomic considerations. In DeerKBS, there are four subtasks: assessments of deer population, deer habitat, SCC, and weather conditions. There are eight attributes related to the four subtasks. These attributes are: (1) deer population size, (2) buck percentage in the population, (3) deer habitat quantity, (4) deer habitat quality, (5) deer population size expected by deer hunters, (6) deer population size expected by farmers, (7) deer population size expected by other interest groups, and (8) winter severity.

The outcomes of assessment for all attributes are listed in Table 1. For example, the outcomes of assessment for deer population density are low, good, or high. Once the assessment for each attribute is finished, further assessment for some attributes can be performed to obtain a higher level of assessment. For instance, habitat quantity can be lacking, average, or abundant; and habitat quality can be poor, medium, or high. The outcomes for overall habitat are assessed as poor, moderate, or excellent (Table 1).

*2.3.3.2. Knowledge acquisition*. Knowledge acquisition is the process of obtaining knowledge from experts and literature. We acquired knowledge from experts by interviewing MDNR deer managers and biologists as well as from literature and the MDNR reports. The knowledge is represented as decision rules. For example,

**Rule I.** IF population density is high, and habitat condition is moderate or poor, and social carrying capacity is fewer deer THEN recommend harvesting more deer.

We used typical management scenarios as examples (referred to as example table) to generate other possible combinations of attributes (referred to as truth table). Based on these tables, decision trees were created by induction. If the information or knowledge was not available for generating rules, we made some educated guesses.

Table 1
Attributes in DeerKBS and their assessment outcomes

| Attributes | Outcomes | Outcomes at a higher level |
|---|---|---|
| Deer population density | Low, good, high | |
| Buck percentage | Low, average, high | |
| Habitat quantity | Lacking, average, abundant | Poor, moderate, excellent |
| Habitat quality | Poor, medium, high | |
| Hunters' expectation | Fewer, same, more | Fewer, same, more |
| Farmers' expectation | Fewer, same, more | |
| General public's expectation | Fewer, same, more | |
| Winter severity | Favorable, average, harsh | |

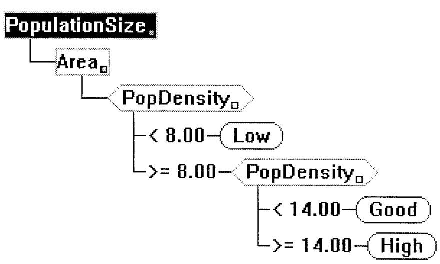



Fig. 1. Subtask for population size assessment, where PopulationSize represents population size, and PopDensity refers to population density (deer/km$^2$).

*2.3.3.3. Knowledge validation*. Testing the knowledge base involves examining the correctness and completeness of the overall knowledge base. Tests were performed at two levels. The first level was the validation of each individual decision rule. We presented the attributes for each rule to deer managers and then compared the decisions from them and from DeerKBS. The second level was the validation of all rules to eliminate those which were redundant and conflicting. The decision tree that XpertRule induced from the example table could detect conflicting rules visually, so the completeness of knowledge base could be guaranteed. During the development of DeerKBS, we also demonstrated the system to deer biologists and wildlife managers in the Wildlife Division of the MDNR, compared the decision results from them and from DeerKBS, and requested their suggestions for system improvement.

### *2.3.4. System implementation*

In DeerKBS, the deer management decision-making task is structured into four subtasks: assessments of population, habitat, SCC, and weather. Once these subtasks are finished, pertinent harvest recommendations are made. The recommendations are further refined by considering the percentage of bucks in the deer population.

*2.3.4.1. Subtask for assessing population*. Population assessment includes the evaluation of population and structure, which are vital parameters in deer management because they are the basis for decision-making. The management objective for population size in the UP of Michigan is 372,500 in the fall, or an average density of 9 deer/km$^2$ ($\sim$23 deer/mi$^2$) (MDNR, 1993). In DeerKBS, deer population density is classified as high if it is above 14 deer/km$^2$ ($\sim$35 deer/mi$^2$), low if below 8 deer/km$^2$ ($\sim$20 deer/mi$^2$), and good if between 8 and 14 deer/km$^2$ ($\sim$20–35 deer/mi$^2$) (Fig. 1).

Population structure is the other aspect of population assessment. As the deer population increases, there are more hunting opportunities for deer hunters and more recreational opportunities for the general public. However, the cost of abundant deer is high in some areas. Too many deer cause unacceptable crop damage (Allen and Mc-

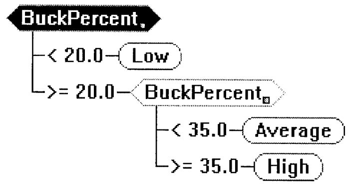



Fig. 2. Subtask for antlered buck percentage assessment, where BuckPercent represents the percentage of antlered buck in deer population.

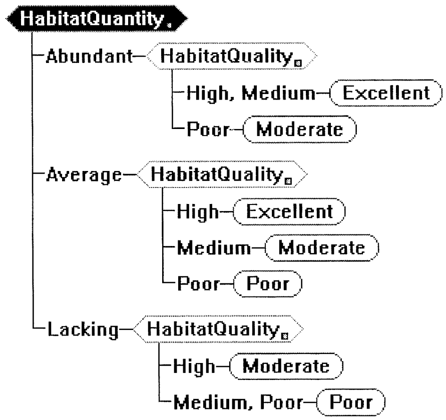



Fig. 3. Subtask for habitat assessment, where HabitatQuantity represents habitat quantity, HabitatQuality represents habitat quality; Abundant, Average, and Lacking are the outcomes of habitat quantity assessment; High, Medium, and Poor are the outcomes of habitat quality assessment; Poor, Moderate, and Excellent are the outcomes of habitat assessment.

Cullough, 1976; Conover and Decker, 1991) and deer-vehicle accidents (Conover et al., 1995), transmit disease (Wilson and Childs, 1997), and adversely impact forest regeneration (Alverson et al., 1988). To improve the quality of deer hunting and to minimize the negative impact of high deer densities, deer management in Michigan is aimed at producing a higher proportion of bucks within a scenario of a lower deer population. One of the objectives of deer management in Michigan is to have 35% of antlered bucks in the deer population. In DeerKBS, the percentage of antlered bucks (or buck ratio) is classified as high if it is above 35, low if below 20, average if between 20 and 35 (Fig. 2).

*2.3.4.2. Subtask for assessing habitat*. There are many approaches to assessing deer habitat. If management recommendations need to be made at the landscape level, landscape analysis can give an overall habitat assessment using some landscape metrics such as edge density. However, deer biologists and deer managers often assess the habitat on a much smaller scale (Krefting and Phillips, 1970; Ozoga et al., 1994; Braun, 1996) using habitat assessment procedures (Short, 1986; Bender and Haufler, 1990). In DeerKBS, habitat quantity is evaluated as lacking, average, or abundant. Habitat quality is evaluated as poor, medium, or high. Overall habitat is evaluated as poor, medium, or excellent (Fig. 3). For example,

**Rule II.** IF habitat quantity is abundant, and habitat quality is high or medium, THEN overall habitat is excellent.

*2.3.4.3. Subtask for assessing social carrying capacity*. Social carrying capacity is the wildlife population level that is acceptable to people (Decker and Purdy, 1988; Minnis, 1996). Measuring public attitudes has been a subject of considerable interest to managers (Arthur and Wilson, 1979). Biologists usually consider only biological carrying capacity, but it is critical to consider social carrying capacity in the management decision-making process (Strickland et al., 1994). The population objectives imposed by SCC are often well below those imposed by BCC. For example, on some farmlands in Wisconsin, SCC is about 12 deer/km$^2$ ($\sim$31 deer/mi$^2$) while BCC is about 40 deer/km$^2$ ($\sim$104 deer/mi$^2$) (McCaffery, 1989). As expected, SCC is highly subject to how much weight the decision-makers put on each stakeholder's preferences. In a region where deer hunters are well organized, deer hunters may exert greater influences than other interest groups in the decision-making process. On the other hand, in a region where farmers are well organized, farmers may have more impact than other interest groups in shaping deer management decisions. In DeerKBS, deer hunters, farmers, and other interest groups (general public) are considered to be the major stakeholders. The expected deer population size for each group is evaluated to have more, the same number of, or fewer deer. Once the assessment for each stakeholder is completed, the overall SCC is evaluated to have more, the same number of, or fewer deer compared with the previous years (Fig. 4). For example,

**Rule III.** IF deer hunters expect to have more deer, and farmers expect to have fewer deer, and general public expect to have fewer deer, THEN overall SCC is to have the same number of deer.

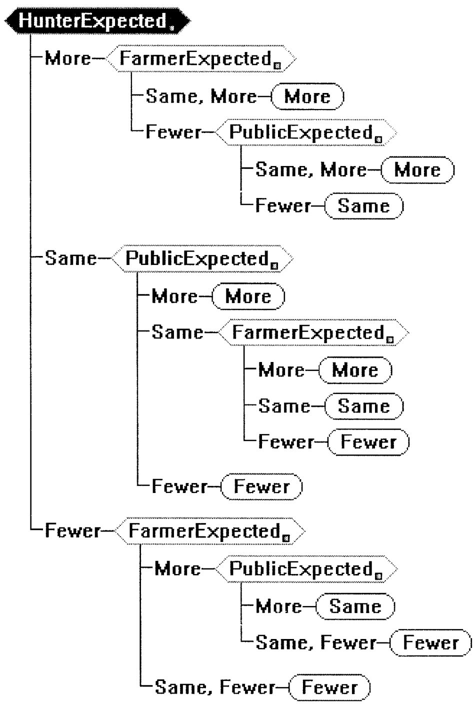



Fig. 4. Subtask for SCC assessment, HunterExpected, FarmerExpected, and PublicExpected represents the expectation for deer numbers by hunters, farmers, and the general public. Fewer, Same, and More are the outcomes of SCC assessments.

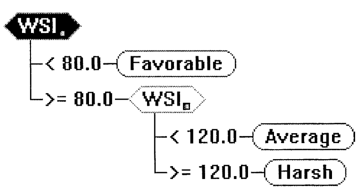



Fig. 5. Subtask for winter weather assessment, Favorable, Average, and Harsh are the outcome of the assessment of winter conditions.

In this rule, more weight was put on the expectation of deer hunters and less weight on the expectation of farmers and the general public. In other words, not every stakeholder was given the same consideration. If equal weight had been given to each stakeholder in this example, the outcome should have favored the groups who expected fewer deer because two groups expected fewer deer and only one group expected more deer. These rules could be easily changed to reflect the reality of the decision-making process.

*2.3.4.4. Subtask for assessing weather*. Many environmental variables affecting deer movement and food availability influence deer population dynamics. For example, winter conditions are a critical factor in the UP of Michigan, impacting deer mortality and reproductivity (Verme, 1969; Xie et al., 1999). Historically, the winter severity index (WSI) in the UP ranged from about 50 to 150 with an average of approximately 100. In DeerKBS, weather conditions are evaluated as favorable if WSI is below 80, harsh if above 120, and average if between 80 and 120 (Fig. 5).

*2.3.4.5. Decision tree and task for decision making*. Putting all the decision rules together, a decision tree is generated and part of the decision tree is shown in Fig. 6. The tree structure offers the control strategy and the nodes allow for inferences. Each node, represented as a hexagon in Fig. 6, determines which lower node will be searched. Each leaf, represented as an ellipse in Fig. 6, indicates a solution. For example, if population density (node PopulationDensity) is high, DeerKBS will evaluate habitat (node Habitat). If habitat is poor, then a recommendation is made to harvest more deer (leaf More). If habitat is excellent, then SCC (node SocialCarryingCapacity) is further considered, and harvest recommendations (leaf Same or More) are made based on the outcome of SCC evaluations.

An emerging feature in the decision tree is that not all decision outcomes follow the same path, as demonstrated in the aforementioned example and in Fig. 6. This feature mimics some decision-making processes in deer management. For example, if population density is high and deer habitat is

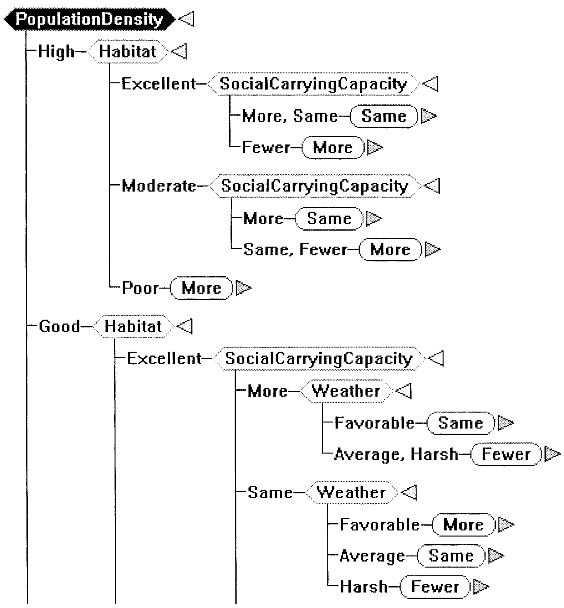



Fig. 6. Part of a decision tree showing how a preliminary recommendation was made based on the outcomes of assessments of deer density, habitat conditions, social carrying capacity, and weather conditions. Note that hexagon represents node and ellipse represents leaf (outcome). Left-pointed triangles represent backward chaining, and right-pointed ones represent forward chaining.

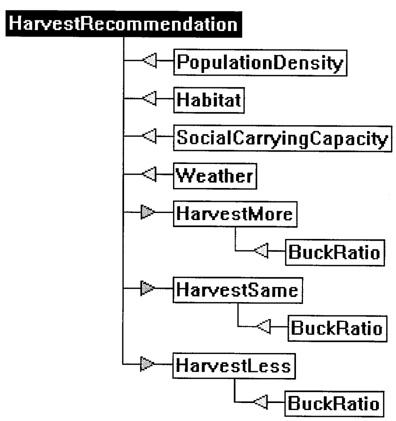



Fig. 7. Diagram of a decision-making procedure. HarvestRecommendation represents the preliminary harvest recommendations that were made based on the assessments of population density, habitat, SCC, and weather. The recommendations were further refined by considering antlered buck percentage in deer population. Note that left-pointed triangles represent backward chaining, and right-pointed ones represent forward chaining.

poor, wildlife managers may recommend harvesting more deer without considering SCC to maintain long-term deer population sustainability.

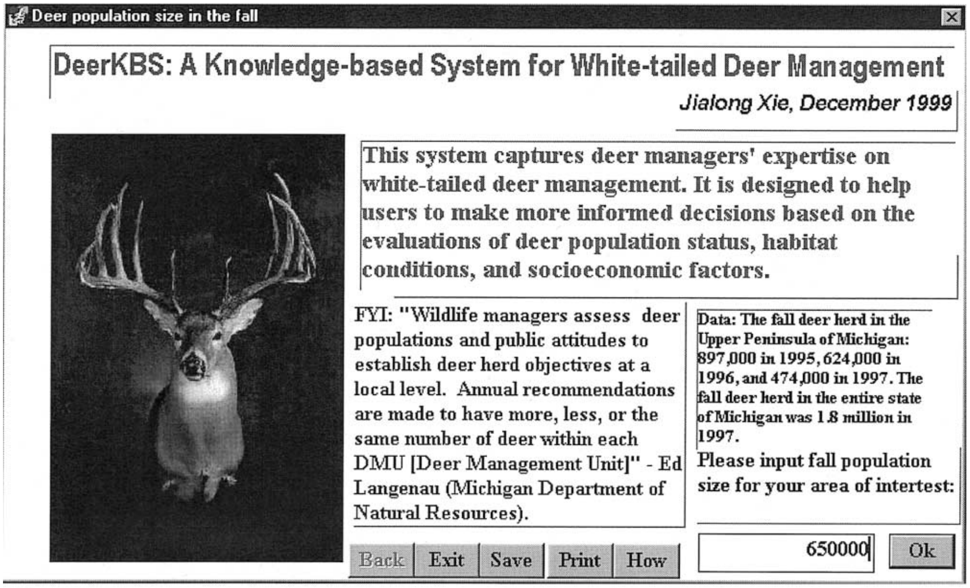
*2.3.4.6. Decision procedure.* Deer managers assess deer populations and habitat conditions as well as public attitudes to establish deer management objectives and annual recommendations are made to have more, fewer, or the same number of deer in the context of previous years' deer management practices. All harvest quotas are compared with previous years' quotas. Then deer managers recommend hunting licensee quotas for antlered bucks and antlerless deer based on their experience in previous years and the management agency's policies, goals, and mission.

DeerKBS simulates deer managers' decision-making processes. Preliminary recommendations are made based on all the outcomes of assessments of population density, habitat conditions, SCC, and weather conditions. DeerKBS then refines its management recommendations by considering the buck ratios in the deer population (Fig. 7). For example,

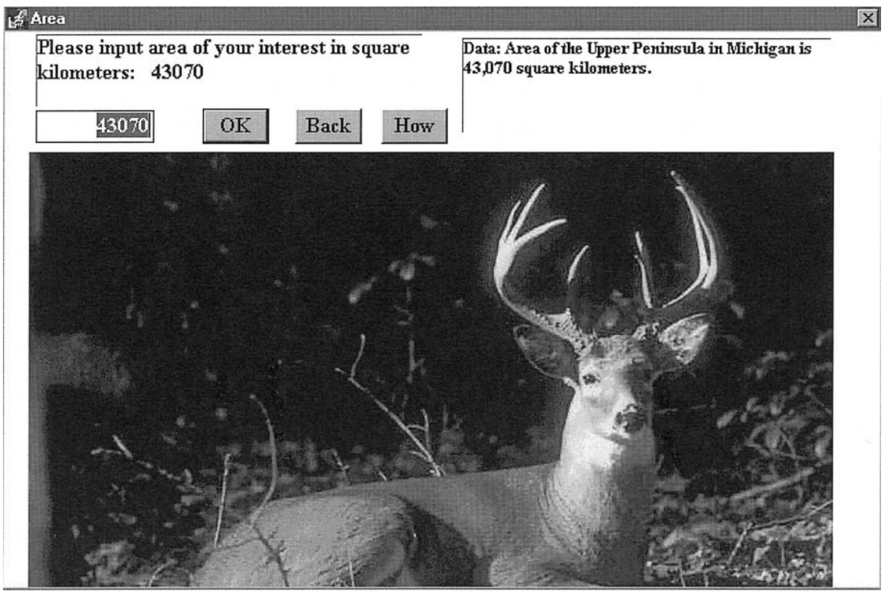
**Rule IV.** IF preliminary recommendation is to harvest more deer, and buck ratio is low, THEN recommend harvesting more antlerless but fewer bucks.

### 2.3.5. Operation and delivery of DeerKBS

DeerKBS works under the Microsoft Windows® environment using XpertRule (Attar Software Ltd, 1996). Background data, information and graphics are incorporated into the user interface (Fig. 8). The explanation mechanism, which is built in XpertRule KBS, keeps track of the decision process. The user can use this feature to understand how DeerKBS works. DeerKBS can be modified through example tables or decision trees. System inputs include attributes of deer population size, size of interest area, evaluation results for habitat quantity and quality, evaluation results of expected deer population size for deer hunters, farmers, and other interest groups, percentage of antlered bucks, and WSI. Through dialogs, users input numbers for numerical attributes or select a choice from a list of values for qualitative attributes. System output is a set of harvest recommendations based on the assessment of the attributes. The output can be printed out or saved into a file.

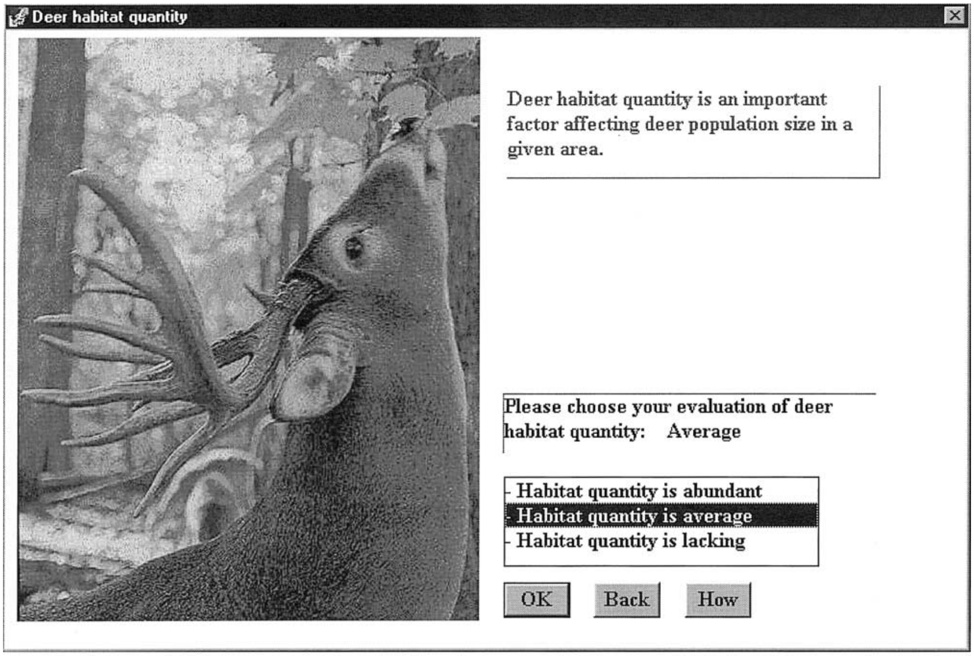



(a)

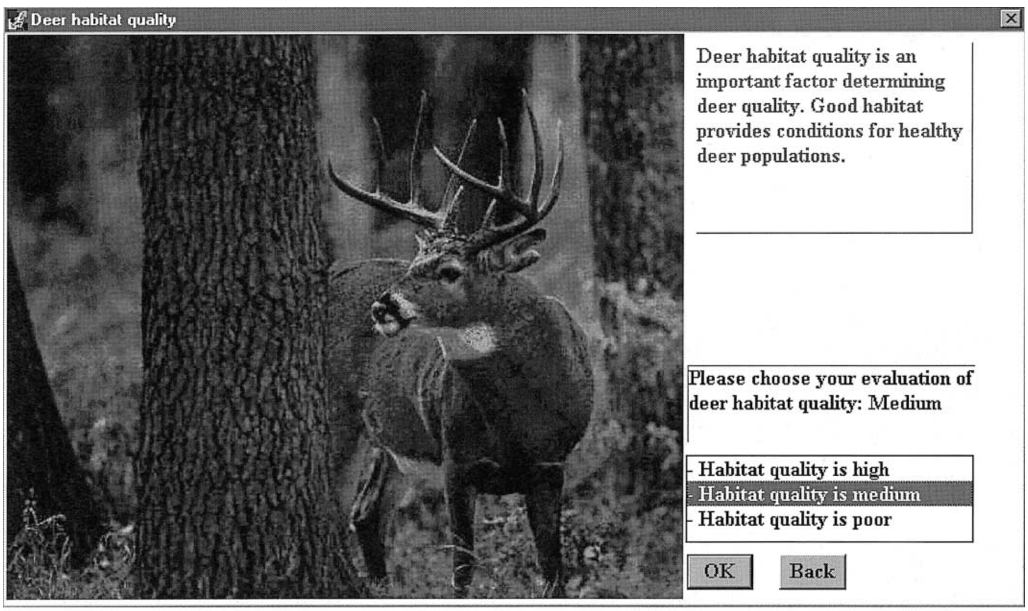



(b)

Fig. 8. Graphic user interface illustrated by a sample simulation. Model Input (a-h): (a) Population Size, (b) Area of Interest, (c) Habitat Quantity, (d) Habitat Quality, (e) Deer Hunters' Expectation, (f) Farmers' Expectation, (g) The General Public's Expectation, (h) Percentage of Bucks in the Deer Population; (i) Final Recommendation; and (j) Explanation of the Decision-making Process. (See text for more descriptions.)




(c)




(d)

Fig. 8. (*Continued*)

DeerKBS can be delivered to users as a binary file with or without password protection. End users can use XpertRun (the XpertRule KBS run time program from Attar Software Ltd) to run DeerKBS. The knowledge base in DeerKBS can be exported to production rules as a text file or a

Visual BASIC function code. Therefore these rules can be embedded in other programs as an intelligent agent (Prerau et al., 1997).

## 3. A sample simulation

In order to demonstrate how DeerKBS works,

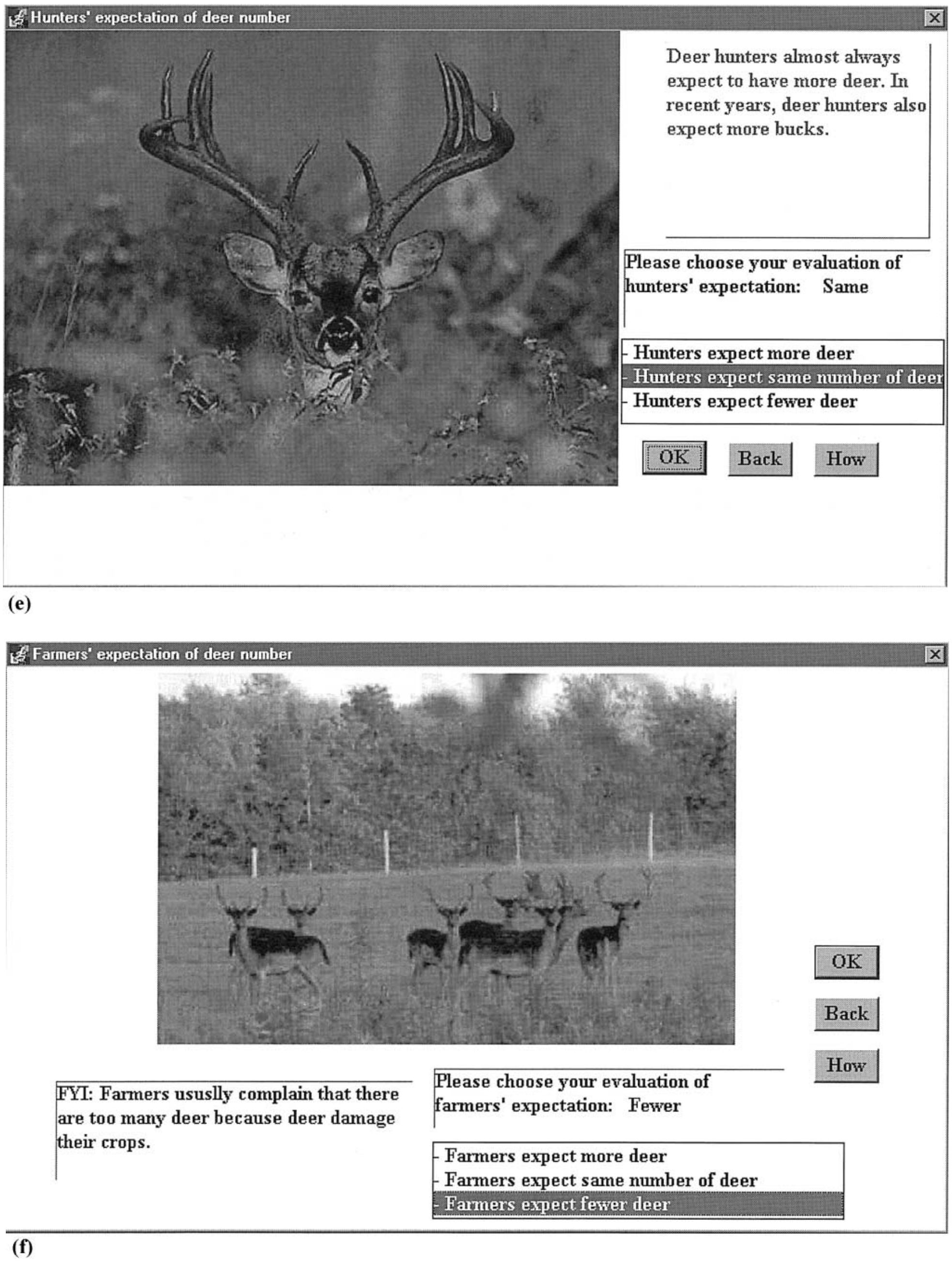
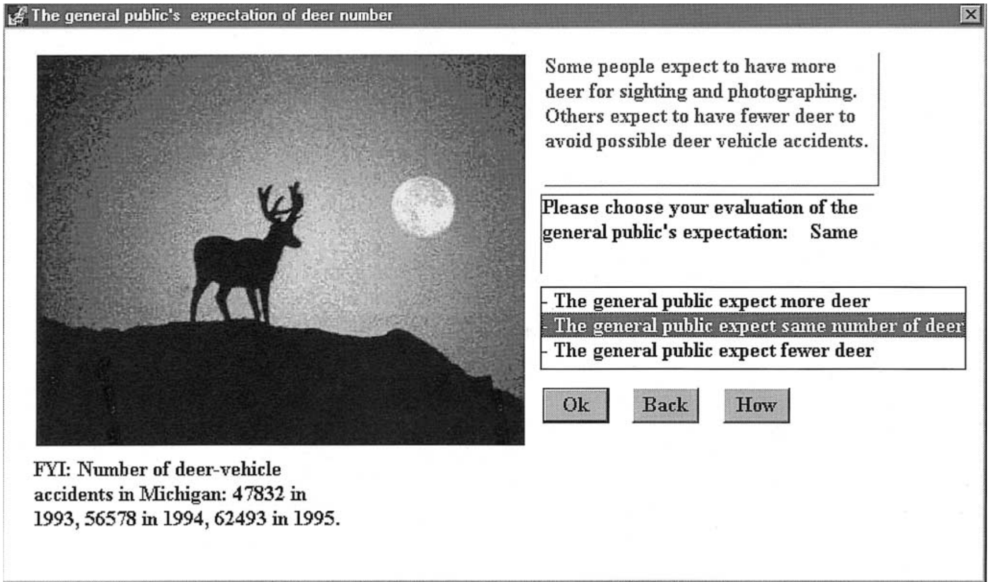
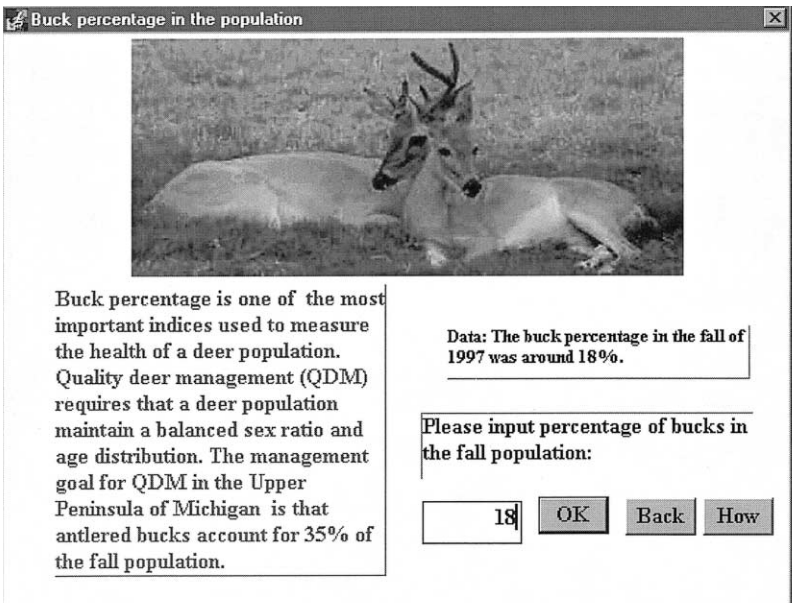



Fig. 8. (*Continued*)




(g)

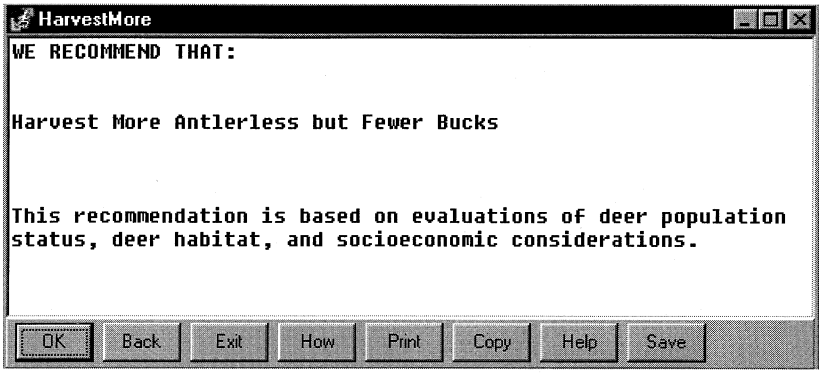



(h)

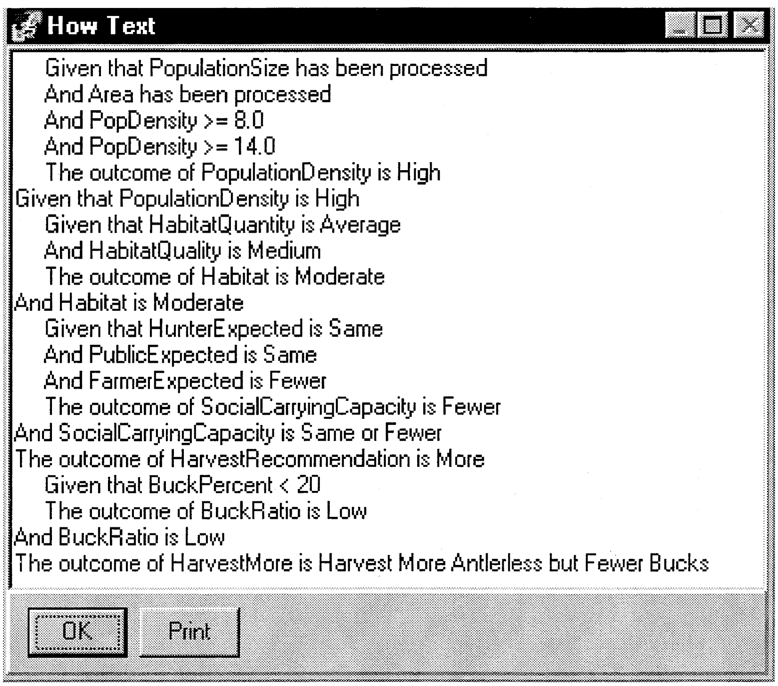
Fig. 8. (*Continued*)

we present a case simulating the process for making recommendations to harvest white-tailed deer in the UP of Michigan. The recommendations are aimed at controlling the deer population, increasing buck ratio, and balancing the needs among different stakeholders.

After DeerKBS is launched, it first prompts the user to enter population size (Fig. 8a). Once the user types in the population size (e.g. 650 000) and clicks the OK button, the system prompts for the area of interest (Fig. 8b). After the user types in the area (43 070 $km^2$ for the UP), the system calculates the population density as 15 deer/$km^2$, and evaluates population density as high according to the population evaluation criteria built in DeerKBS. DeerKBS then prompts the user to evaluate habitat quantity. After the user chooses 'Habitat quantity is average' and clicks the OK button (Fig. 8c), DeerKBS prompts the user to evaluate habitat quality. If the user chooses 'Habitat quality is medium' and clicks the OK button (Fig. 8d), the system concludes that the overall habitat is moderate. DeerKBS then prompts the user to evaluate deer hunters' expectations (Fig. 8e), farmers' expectations (Fig. 8f), and the general public's expectations (Fig. 8g) (More, Fewer, and Same, respectively). After the system finishes all three aspects of evaluation, it concludes that the social carrying capacity is to




(i)




(j)

Fig. 8. (*Continued*)

have more deer. Based on the population density, deer habitat and social carrying capacity, DeerKBS concludes that the same number of deer as in the previous year should be harvested. DeerKBS then prompts the user for the buck percentage in the population. Once the user types in 18 percent and clicks the OK button (Fig. 8h), the system makes final recommendation as 'Harvest More Antlerless Deer but Fewer Bucks' (Fig. 8i). By clicking the 'How' button on the recommendation screen (Fig. 8i), the decision-making process can be seen (Fig. 8j).

## 4. Conclusions and discussion

DeerKBS integrates major ecological and socioeconomic factors (e.g. deer population and habitat conditions, and the needs of different interest groups) into the decision-making process and provides a unifying decision-making framework for deer management. In DeerKBS, the task of deer management decision-making is divided into an array of decision-making subtasks. These structured decision subtasks can help decision-makers better utilize knowledge and expertise from different fields. The final decisions depend on input from experts in deer population, habitat, and human dimensions. Thus the decisions are more informative, democratic, reliable, and effective than those made by a single specialist (Schmoldt and Rauscher, 1996).

Wildlife managers sometimes have to make decisions even with incomplete/qualitative data and change management strategies when new information becomes available. The 'top down' technique used in building DeerKBS offers the flexibility to include more information when possible. For some subtasks such as habitat assessment, only attributes at the highest level were included because data for lower levels were not available. If there is more detailed information available, another level of details could easily be incorporated into the system. For example, if a specific area has been sampled and the biomass for each type of food can be estimated, the total amounts of food can be calculated and used in the assessment of habitat quantity. The amount of preferred food for deer can also be estimated and then habitat quality can be evaluated. If a habitat suitability index (HSI) and landscape metrics such as edge density (Xie, 1999) are available for a specific area, a decision tree can be added to convert the numerical HSI and landscape metrics to habitat assessment.

The biggest challenge in developing and applying DeerKBS is to elicit the knowledge of experts and to test the validity of its knowledge base. Although there are many interview techniques (Guida and Tasso, 1994) to stimulate the expression of knowledge and expertise, most of these techniques are time-consuming and require rich personal experience. So DeerKBS relies much on written documents. The knowledge elicited must be appropriately verified (Guida and Tasso, 1994) by deer managers. However, some wildlife managers are reluctant to express and share their decision-making processes. Like other KBS applications, the validity of recommendations from DeerKBS is dependent on the validity of the decision rules in the knowledge base. It is not easy or possible to validate the decision rules fully, as the rules are not universal. Each manager has his or her own 'rules of thumb' in practice, making cross-examination more difficult. Furthermore, the rules in the knowledge base need to be modified to reflect heterogeneity across space and time. For example, winters in southern Michigan are much warmer than in the UP, so the evaluation criteria for those conditions should be changed accordingly.

Communication between managers and stakeholders is important to achieve management objectives effectively (Kellert, 1994). Stakeholders often want to be involved in the decision-making process. However, deer managers lack an instrument to communicate effectively with stakeholders. DeerKBS can be an effective communication tool for deer managers to present their decision-making processes to stakeholders. For wildlife management agencies, DeerKBS can be an effective tool to standardize the management decision procedures. When this system was demonstrated to the wildlife biologists and managers at the Wildlife Division of the MDNR, it was considered useful to standardize the diverse management decision processes happening in field offices of the MDNR. Thus, the use of DeerKBS can enhance management accountability and improve collaboration among managers, scientists and other stakeholders.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