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Protocol and Practice in the Adaptive Management of Waterfowl Harvests

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ABSTRACT

Waterfowl harvest management in North America, for all its success, historically has had several shortcomings, including a lack of well−defined objectives, a failure to account for uncertain management outcomes, and inefficient use of harvest regulations to understand the effects of management. To address these and other concerns, the U.S. Fish and Wildlife Service began implementation of adaptive harvest management in 1995. Harvest policies are now developed using a Markov decision process in which there is an explicit accounting for uncontrolled environmental variation, partial controllability of harvest, and structural uncertainty in waterfowl population dynamics. Current policies are passively adaptive, in the sense that any reduction in structural uncertainty is an unplanned by−product of the regulatory process. A generalization of the Markov decision process permits the calculation of optimal actively adaptive policies, but it is not yet clear how state−specific harvest actions differ between passive and active approaches. The Markov decision process also provides managers the ability to explore optimal levels of aggregation or "management scale" for regulating harvests in a system that exhibits high temporal, spatial, and organizational variability. Progress in institutionalizing adaptive harvest management has been remarkable, but some managers still perceive the process as a panacea, while failing to appreciate the challenges presented by this more explicit and methodical approach to harvest regulation. Technical hurdles include the need to develop better linkages between population processes and the dynamics of landscapes, and to model the dynamics of structural uncertainty in a more comprehensive fashion. From an institutional perspective, agreement on how to value and allocate harvests continues to be elusive, and there is some evidence that waterfowl managers have overestimated the importance of achievement−oriented factors in setting hunting regulations. Indeed, it is these unresolved value judgements, and the lack of an effective structure for organizing debate, that present the greatest threat to adaptive harvest management as a viable means for

coping with management uncertainty.

KEY WORDS: adaptive management, harvest, hunting regulations, Markov decision process, migratory birds, optimization, uncertainty, waterfowl.

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INTRODUCTION

As experience with adaptive resource management grows, the barriers to its successful implementation become increasingly apparent. Certainly, recent reviews (e.g., McLain and Lee 1996, Walters 1997) would not encourage many managers to pursue an approach that typically is associated with difficult concepts and methodologies, with problems of high biological and sociological dimension, and with institutional resistence (Walters 1986). Our recent experience with the adaptive management of U.S. waterfowl harvests confirms the ubiquitousness of these barriers; however, it also demonstrates that they can be partially overcome. Although few efforts in adaptive management have proceeded beyond the planning phase (Walters 1997), state and federal managers in the United States have used an adaptive approach to setting duck hunting regulations since 1995. Although the approach is not "experimental" in the traditional sense, there is an explicit accounting for uncertain regulatory impacts, as well as the recognition that harvest policy can be an effective tool for reducing those uncertainties. Those of us involved in this effort understand the formidable barriers to continued progress, but we benefit from an institutional commitment to adaptive management that so often has eluded other natural resource managers. Thus, in the regulation of waterfowl harvests, there is hope that adaptive resource management may live up to its promise of delivering improved understanding and management performance.

In this article, we present a conceptual model for the adaptive management of waterfowl harvests and discuss its application in the United States. We also provide a description of some of the technical and institutional issues that continue to challenge managers of waterfowl harvests. We hope that our experience will be useful to those attempting to use adaptive resource management in ecologically complex, multi−jurisdictional systems.

BACKGROUND

There are 43 species of ducks, geese, and swans (Anatidae) native to North America, and their breeding, migration, and wintering ranges encompass virtually every ecosystem on the continent (Bellrose 1976). Each year, roughly 20 million waterfowl are harvested for sport, and largely unknown numbers are harvested for subsistence. Some 70−80% of the waterfowl harvest consists of ducks, principally Mallards (*Anas platyrhynchos*), teal (*A. crecca*, *A. discors*), and Wood Ducks (*Aix sponsa*). Most of the two million waterfowl hunters in North America reside in the United States, where the bulk (85%) of the sport harvest occurs. Direct expenditures by hunters in the United States exceed U.S.$500 million, and the total economic benefit of waterfowl is estimated at U.S.$11 billion annually (Teisl and Southwick 1995).

Prior to 1916, regulatory authority over waterfowl harvests was vested with state and provincial governments. The resulting variability in regulatory approaches and the lack of coordination made effective management virtually impossible. In 1916, Great Britain (for Canada) and the United States signed the Convention for the Protection of Migratory Birds, which vested management authority for migratory birds with the federal governments of the signatory countries. Subsequent treaties with Mexico, Japan, and the U.S.S.R. broadened and strengthened the role of federal governments in regulating harvest. The treaties effectively ended commercial hunting, prohibited all take of migratory birds from 10 March to 1 September each year, and provided for hunting seasons not to exceed 3.5 months. Only recently have efforts been made to amend the treaties to officially recognize and regulate subsistence harvest.

The system of waterfowl harvest management in North America has evolved into what may be the most extensive, complex, and costly wildlife conservation effort in the world (Hawkins et al. 1984). Four Flyway Councils, consisting of representatives from state and provincial wildlife agencies, provide a forum for reviewing biological information and for developing regulatory proposals for consideration by federal governments. Based on this input, federal harvest guidelines are established and hunting regulations are then promulgated on a state or provincial basis. Hunting regulations typically specify season dates, daily bag limits, and legal methods of take. The United States has by far the most complex system of public announcements, deliberations, and regulatory decision making (Blohm 1989).

An essential component of the regulatory process consists of data collected each year on breeding population status, harvest levels, production, migration, and other population characteristics (Smith et al. 1989). Long−term data are used to estimate key population parameters such as survivorship and reproduction, and to associate levels of harvest with various regulatory scenarios (Martin et al. 1979). This information is incorporated into population models, which in turn are used to inform the regulations process (Williams and Nichols 1990).

Not surprisingly, the modeling of harvest impacts is characterized by great uncertainty (Nichols et al. 1995), but models often have been used without adequate appreciation of their limitations (Conroy 1993). Opportunities to reduce uncertainty through the regulatory process have not been exploited. An unfortunate result has been an unnecessarily slow rate of learning about population dynamics and harvest impacts, and a correspondingly slow rate of improvement in management over time. During the 1980s, the U.S. Fish and Wildlife Service called for a more informative approach to harvest regulation, and even implemented a large−scale harvest−management experiment (Sparrowe and Patterson 1987, U.S. Fish and Wildlife Service 1988). Unfortunately, that experiment was broadly criticized and momentum for a more adaptive approach to management was lost.

The impetus for improved decision making grew again in the 1990s, when dramatic fluctuations in midcontinent duck populations prompted new controversy about appropriate harvest levels. The crisis provided an opportunity for some institutional introspection, as managers sought the means to make more objective decisions in the face of pervasive uncertainty (Johnson et al. 1993). Subsequent improvements in the regulatory process were framed in terms of adaptive resource management, in which there is an explicit accounting for uncertainty and for the influence of management in reducing that uncertainty (Williams and Johnson 1995, clickhere for an on−line copy of this reference). Since 1995, duck hunting regulations in the United States have been prescribed by a formal process referred to as adaptive harvest management (clickhere to access annual status reports on adaptive harvest management).

A PROTOCOL FOR ADAPTIVE WATERFOWL HARVEST MANAGEMENT

Long−standing deficiencies in waterfowl harvest management have included a lack of well−defined objectives, a failure to account for uncertain management outcomes, an overly subjective and complicated decision−making process, and inadequate feedback mechanisms. To address these shortcomings, we sought a management approach that would:

1. evaluate management actions based on explicit definitions of benefits (and costs, where necessary);
2. account for the dynamic nature of waterfowl populations and the influence of management actions on those dynamics;
3. permit management actions to be constrained by economic, social, or political factors;
4. account explicitly for uncertainty as to the effects of management actions and uncontrolled

environmental factors;
5. define explicit linkages between management policies and operational monitoring and assessment programs;
6. incorporate feedback mechanisms by which management performance could be improved over time; and
7. unify waterfowl harvest management across temporal, spatial, and bio−organizational scales.

To meet these needs, harvest management was framed in terms of sequential decision making under uncertainty, more particularly in terms of stochastic control processes (Puterman 1994). In this conceptual model, the manager periodically observes the state of the system (e.g., population size and relevant environmental features) and takes some management action (e.g., hunting regulations). Based on this action, the manager receives immediate benefits and incurs costs that are relevant to the stated objectives of management. The resource system subsequently evolves to a new state, with the change being influenced by the management action and other uncontrolled factors. The manager then observes the new system state and makes a new decision. The goal of management is to make a sequence of such decisions, each based on information about current system status, so as to maximize benefits and/or minimize costs over an extended time frame. A prescription of optimal management actions for each state of the system at each time constitutes an optimal management policy.

By taking advantage of the Markovian nature of decision making and system behaviors in waterfowl management, it is possible to characterize adaptive harvest management in terms of a Markov decision process. Thus, management actions, rewards, and system transitions need only be described in terms of current system state and action, and not on states occupied or actions taken in the past. By carefully modeling population responses to management, limiting the number of management options, and accounting for stochastic effects and system uncertainties, we are able to identify action−specific transition probabilities and returns needed to use the optimization algorithms available for Markov decision processes (Puterman 1994).

Four fundamental sources of uncertainty can be identified in the regulations−setting process (Williams 1997). The first and most obvious is uncontrollable environmental variation. A second source is partial controllability, which expresses a lack of concordance between intended and actual management controls, as a result of indirect actions (e.g. harvest regulations) that are imprecisely linked to specific control levels. A third source of uncertainty is structural, in that managers face an incomplete understanding of biological and ecological processes. Finally, partial observability reflects the fact that all parameters of management interest can be known only within the precision afforded by extant monitoring programs. All four sources of uncertainty ultimately limit the ability of managers to respond appropriately and effectively to changes in system status, or to understand the underlying causes of those changes. Of course, the limitations on management are magnified by the simultaneous presence of multiple sources of uncertainty (Williams et al. 1996).

Passive adaptation

Regulatory policies governing waterfowl harvests currently are identified using a recursive algorithm, in which the expected utility (or value) of harvest $V(\underline{R}_t \mid \underline{X}_t)$ over the time frame [$t, t+1, ..., T$] is conditioned on system state$\underline{X}_t$ at time t, with $\underline{R}_t$ being a strategy of time−specific and state−specific regulatory decisions (Johnson et al. 1997):

$$\begin{aligned} V(\underline{R}_t|\underline{X}_t) &= \sum_i p_{i,t}\left[E\left[\sum_{\tau=t}^{T} u_{i,\tau}|\underline{X}_t\right]\right] \\ &= \sum_i p_{i,t}\left[E\left[u_{i,t}|\underline{X}_t + \sum_{\tau=t+1}^{T} u_{i,\tau}|\underline{X}_t\right]\right] \quad (1) \end{aligned}$$

where $u_{i,t}$ is a model−specific harvest utility and and $p_{i,t}$ represents the probability that model i is the most appropriate model of system dynamics. The expectation (E) is taken with respect to environmental variation and partial controllability, using empirical probability distributions. Note the explicit trade−off between expected present and future harvest utilities. Note also that the algorithm for passive adaptation computes weighted averages of both present and future utilities, based on current model probabilities. Operationally, the aggregate utilities are generated with a single model that is formed by averaging model−specific utilities at time t and state transition probabilities from time t to $t+1$, based on $p_{i,t}$.

An optimal regulatory policy is one that maximizes the expected cumulative harvest utility, $V(\underline{R}_t|\underline{X}_t)$. Harvest utility may be defined simply as harvest yield, or as a function of harvest and other performance metrics, such as waterfowl population size (Johnson et al. 1997). For example, Mallard harvest managers seek to maximize long−term cumulative harvest, but proportionally devalue harvests whenever population size is expected to fall below the goal of the North American Waterfowl Management Plan:

$$u_{i,t} = \begin{cases} h_{i,t}, & \text{if } E(X1_{i,t+1}) \geq g \\ h_{i,t} \cdot [E(X1_{i,t+1}) \div g], & \text{if } E(X1_{i,t+1}) < g \end{cases} \qquad (2)$$

where $h_{i,t}$ is the model−specific annual harvest, $X1_{i,t+1}$ is the model specific size of the subsequent Mallard breeding population, and g is the population goal. Defining harvest utility in this way decreases the likelihood of regulatory decisions that are expected to produce population sizes below the goal. Of course, harvest utility also should account for costs, but this has not been necessary in waterfowl harvest management because the cost of promulgating hunting regulations does not depend on the nature of the regulatory decision.

A key feature of the passively adaptive process is an explicit accounting for different hypotheses about the effects of regulations and other environmental features on population dynamics. Thus, the optimal regulatory decision in year t is conditioned on both system state$\underline{X}_t$ and the probabilities assigned to a set of alternative system models. Given a particular regulatory decision in year t, each model of population dynamics provides a prediction for population size in year $t + 1$. Some models perform better than others, and this performance is assessed by comparing the model−specific prediction of population size with the population estimate derived from the monitoring program. Models that are relatively good predictors gain probability mass according to Bayes Theorem:

$$p_{i,t+1} = \frac{p_{i,t}\, l_i(X1_t, X1_{t+1})}{\sum_i p_{i,t}\, l_i(X1_t, X1_{t+1})} \qquad (3)$$

where 1_i ($X1_t$, $X1_{t+1}$) is the probability of observed changes in population size from t to $t+1$, conditioned on model i (Hilborn and Walters 1992:503−504). This probability is calculated by assuming that observed population sizes will be distributed normally around the prediction (Hilborn and Walters 1992:504, Williams et al. 1996), and by deriving a simulated probability density function of predicted population size (W. Kendall, Patuxent Wildlife Research Center, *personal communication*). These density functions are generated from the structure of model i and from assumed distributions for sampling variation in$\underline{X}_t$ (i.e., partial observability) and variation in harvest rates under a given regulatory decision (i.e., partial controllability).

Thus, the passively adaptive approach is a three−step process:

1) In year t, an optimal regulatory decision is identified, based on current or "prior" model probabilities $p_{i,t}$, and system state$\underline{X}_t$.

2) The regulatory decision having been made, model−specific predictions for population size in year $t + 1$ ($\underline{X}_{i,t+1}$) are determined.

3) When monitoring data from year $t + 1$ are available, model probabilities are updated to reflect the relative performance of the alternative models.

The new or "posterior" model probabilities then become the prior probabilities for the next time step, and are used to derive a regulatory strategy for $\underline{X}_{t+1}$. Thus, harvest policies "evolve" over time in response to changes in the characterization of structural uncertainty.

The process is passively adaptive in the sense that informative changes in model probabilities occur as an unplanned by−product of the regulatory process (Walters 1986). A major advantage of this process over the traditional approach is an explicit accounting for structural uncertainty by using empirical assessments of model probabilities. The primary disadvantage of a passively adaptive process is in the failure to recognize that harvest policy itself can be used as a tool to reduce structural uncertainty.

Active adaptation

The recognition that some regulatory strategies are more informative than others has led to a consideration of more actively adaptive approaches. Development of such policies involves a trade−off between short−term management performance and the long−term value of knowing which alternative model of system dynamics is most appropriate (Walters 1986). Optimal actively adaptive policies can be determined with a generalization of the Markov decision process by expanding the modeled system to include an information state (Williams 1996*a,b*). Temporal transitions in the information state are a function of regulatory actions in the same way that temporal changes in the resource state are a function of actions.

The recursive computing algorithm for active adaptation is:

$$V(\underline{R}_t|\underline{X}_t,\underline{P}_t) = \sum_i p_{i,t}\left[E\left[u_{i,t}|\underline{X}_t\right]\right]+\sum_i \left[E\left[p_{i,t+1}\left(\sum_{\tau=t+1}^{T} u_{i,\tau}|\underline{X}_t,\underline{P}_t\right)\right]\right] . \quad (4)$$

Unlike the algorithm for passive adaptation, only present harvest utilities are weighted by prior model probabilities, whereas future utilities are weighted by posterior probabilities. The idea is to account for the effect of management actions not only on system state$\underline{X}_t$, but also on the information state as characterized by the probabilities $\underline{P}_t$ (the set of $p_{i,t}$ probabilities). In this sense, management actions serve the role of yielding both harvest utility and information about system dynamics.

Recent advances in theory and software have overcome some of the difficulties in computing actively adaptive strategies that are optimal with respect to management objectives (Williams 1996*a,b*; B. Lubow, Colorado Cooperative Fisheries and Wildlife Research Unit, *personal communication*). We have just begun, however, to explore differences between passive and active policies as a function of prior model probabilities, objective functions, time horizons, discount rates, and other system features that may bear on optimal rates of learning. Preliminary investigations with models for Mallard harvest management (Johnson et al. 1997) suggest that the greatest differences in passive and active policies occur when uncertainty is highest, and that no differences occur in the case of model certainty. Optimal actively adaptive policies lacked "probing" (Walters 1986) actions for a wide range of commonly encountered system states, although relatively gentle probes were apparent at extreme system states. Finally, even these probing actions were attenuated when there was an explicit recognition of partial harvest controllability and partial system observability. These results suggest that the passively adaptive protocol may perform nearly as well as the actively adaptive protocol, even when there is a high degree of uncertainty about system dynamics and management impacts.

THE PRACTICE OF ADAPTIVE HARVEST MANAGEMENT

Goal−setting in adaptive harvest management

Natural resource management is a process of using biological information to predict consequences (causation), and sociological information to value those consequences (goals) (Lee 1993). When managers agree on both goals and causation, management decisions can be based on an established routine of gathering and evaluating information. If there is agreement about the effects of management actions, but disagreement about management goals, a process of negotiation among stakeholders is necessary to develop acceptable policy. If management goals are broadly accepted, but there is disagreement or uncertainty about the impacts of management actions, adaptive management can be a useful tool for addressing and resolving these disagreements. In effect, adaptive management allows managers to agree on policy when they cannot agree on predicted outcomes. Seen in this light, adaptive management is not a process for coping with disagreement over management goals and objectives.

It seems obvious that any decision−making process will be limited in its effectiveness if there is ambiguity about the goals or objectives of the process. Yet, much of the history of waterfowl harvest management in North America has been marked by a lack of explicit, unambiguous, and agreed−upon objectives (Nichols et al. 1995). Perhaps because harvested waterfowl are not a commercial commodity, there always has been some reluctance to consider the size of the harvest as the most relevant performance measure. However, most managers have been content to accept that harvest is the product of hunter activity and success, which usually are deemed more appropriate measures of performance. Interestingly, recent human−dimensions studies indicate that hunter participation and satisfaction are not increased substantially by regulations that provide for the maximum allowable harvest (Enck et al. 1993, Ringelman 1997). More disturbing is evidence that managers continue to overestimate the importance of achievement−oriented factors in setting hunting regulations, ignoring the evidence that waterfowl hunters are motivated principally by the social and aesthetic aspects of outdoor recreation (Ringelman 1997).

In hindsight, initial demands for definitive objectives have been somewhat naive because of the inherent complexity and conflicting nature of biological, social, economic, and administrative goals. Moreover, it is apparent that disputes over objectives and beliefs about biological processes have become intertwined (Lee 1993:107, Johnson et al. 1996). Managers' objectives, and the constraints they are willing to accept, are dependent on population dynamics, which is itself a source of uncertainty. To provide structure to the debate, we initially focused on valuations of harvest and population size. We used an iterative process of evaluation, comparison, and modification (Holling 1978) that ultimately produced a broadly supported definition of harvest utility. Ancillary objectives (e.g., minimizing the temporal frequency of regulatory changes), which are less amenable to optimization in a Markov decision process, are being addressed through specification of the discrete regulatory alternatives. For example, regulatory alternatives that produce large differences in expected harvests tend to decrease the frequency of regulatory changes. The computing algorithms previously described have been essential for exploring the implications of these and other objectives and, thus, for permitting more informed debate.

Monitoring and assessment issues in adaptive harvest management

A major advantage of adaptive harvest management over the traditional approach is that it makes explicit the role of resource monitoring in the formulation of harvest strategies. A tighter linkage between monitoring and management allows managers to better evaluate the utility of various survey activities, thus ensuring that management benefits are commensurate with monitoring costs. Given the current fiscal climate in which the utility of many survey programs is being examined critically, it is important that monitoring be integrated with assessment and decision making into a cost−effective program for harvest management.

As well developed as they are, one of the major deficiencies among current waterfowl monitoring programs is a lack of useful information on the landscape features and patterns that underlie population dynamics. A key challenge for a more informed approach to harvest regulation is to identify those landscape features that are relevant to demographic processes, and then to regularly monitor those features at appropriate spatial and temporal scales. Because waterfowl migrate long distances, large−scale, coordinated approaches will be necessary to help identify cross−scale effects in population dynamics. Given the cost of such programs, managers will increasingly need to rely on remotely−sensed data and GIS technologies (Johnson et al. 1996).

The lack of information on the spatial and temporal dynamics of waterfowl habitats may account for the dearth of studies regarding the nature of density dependence in population regulation. Even if more habitat information were available, the extreme mobility of waterfowl makes definitions of density seem tenuous at best. Nonetheless, it is disturbing that the theoretical basis for sustainable exploitation (Hilborn et al. 1995) has received scant attention in waterfowl studies. On a more hopeful note, recent advances in banding and marking programs should stimulate construction of more spatially explicit population models (Nichols 1996), with processes that are linked to the temporal and spatial patterns of landscapes (e.g., Dunning et al. 1992).

A necessary component for both passive and active adaptive management is an agreed−upon procedure for updating the probabilities associated with alternative models of system dynamics. The updating procedure adjusts model probabilities each year, using probabilities from the previous year and the change in population size between years to produce posterior probabilities. This procedure contrasts with the use of long−term information bases such as banding data, for which a comparison of alternative models depends on analysis of historical information extending years into the past. A key difficulty in attempting to identify optimal strategies with the latter approach is that the optimization procedure becomes ever more complex as information accumulates over time, and this complexity can quickly overwhelm available computer resources (Walters 1986:233). A major technical challenge is to develop procedures whereby historical information such as banding data can be folded effectively into the updating of model probabilities.

The scaling of adaptive harvest management

All ecological systems exhibit variability on a broad range of temporal, spatial, and bio−organizational scales as a function, ultimately, of how individuals respond to their environment (Levin 1992). The scale of aggregation for management purposes is an arbitrary decision, but one that can strongly influence both the benefits and costs of management. Management systems that account for important sources of ecological variation are expected to yield the highest benefits, but also are characterized by relatively high monitoring and assessment costs (Babcock and Sparrowe 1989, Sparrowe 1990). Determining the optimal scale for management depends critically on the availability of explicit performance criteria and on descriptions of relevant ecological patterns. The description of ecological patterns, in turn, depends on sufficient data to explore ecological variation and to elucidate underlying causal mechanisms.

We currently are using the passively adaptive process described here to explore optimal levels of aggregation or "management scale" for regulating waterfowl harvests. The utility of this exercise depends on the ability to model temporal, spatial, and bio−organizational variation so that the implications of aggregation can be ascertained. Aggregation can be accommodated both in the specification of stock dynamics and in the spatial and temporal variation of regulatory decisions. Also needed is an explicit accounting of both management benefits and monitoring costs as a function of management scale. When benefits are largely invariant to management scale, consideration of monitoring and assessment costs will motivate managers to "average" or "collapse" harvest policy across sources of ecological variation. When costs are ignored, however, managers are driven toward extreme levels of disaggregation. This latter approach characterizes waterfowl harvest management in the United States, where there has been a persistent effort to account for increasingly more spatial and organizational variation in waterfowl biology. However, our preliminary investigations of management scale raise serious questions about the cost−effectiveness of this approach. In simulation exercises, harvest utility was rather insensitive to the level of management aggregation, even when potential stocks of ducks were characterized by relatively large demographic differences. This lack of sensitivity was even more pronounced in the face of poor control over stock−specific harvests (Johnson and Moore 1996).

CONCLUSIONS

The term "adaptive management" was coined in the 1970s by those concerned with the intrinsic uncertainties in environmental management (Holling 1978). However, the concept of "learning by doing" (Walters and Holling 1990) has been espoused for many years in many forms, often under the rubric of "management by experimentation" (MacNab 1983) or "probing" (Walters 1986). In fact, waterfowl biologists often have advocated experimenting with regulations to help resolve uncertainty about the effect of harvest on annual survivorship (e.g., Hickey 1955, Anderson et al. 1987, Conroy and Krementz 1990). We believe that these pleas usually have been ignored, not because the reduction of uncertainty is considered unimportant, but because of the short−term risks to harvest opportunity that experimentation might entail. In effect, implementation of a regulatory experiment means temporarily replacing traditional harvest objectives with an objective to learn (i.e., to discriminate among alternative hypotheses of system dynamics). As a consequence, there is a potential loss of harvest opportunity with experimentally based regulations.

In contrast, the focus of adaptive harvest management is on neither learning rates nor short−term harvest, but instead on regulations that provide an optimal balance of short− and long−term harvest benefits. Fortunately, the theory, computing algorithms, and software necessary to compute optimal, actively adaptive policies are now available (Williams 1996*a*,*b*). Although the benefit of actively adaptive policies over passive policies (as defined here) remains unclear, we are confident that adaptive optimization will present opportunities to improve management performance (and political acceptance) above and beyond those of a classic experimental approach.

Although the ultimate fate of adaptive harvest management of North American waterfowl remains uncertain, we believe that ancillary benefits are increasingly apparent. The process has provided an effective link between data and decisions by integrating monitoring, assessment, and decision making in a coherent framework. The explicitness demanded by an adaptive approach has helped to focus attention on important biological and social issues and has guaranteed greater accountability in management decisions. A greater acceptance of management uncertainties, combined with more rigorous and focused assessments, has fostered a greater willingness among at least some managers to challenge dogma and traditional beliefs.

The use of adaptive management for regulating waterfowl harvest in the United States is likely to continue, but its long−term viability is by no means assured. It is not yet clear that waterfowl managers will acknowledge the limits to performance imposed by uncertainty and act accordingly. Nor is it clear that managers are prepared to invest the same energy and resources in collecting information on resource users as they have on the resource itself, even if it means management objectives remain ill−defined and unmet. Ultimately, the success of adaptive harvest management depends on a general agreement among stakeholders about how to value harvest benefits and how those benefits should be shared. Revisions to the Canadian Constitution, and subsequent efforts to amend treaties to legalize spring hunting for subsistence, portend vast changes to the structure of the decision−making process. In effect, more stakeholders, including aboriginal peoples and provincial governments, probably will demand a stronger role in the decision−making process. It is incumbent upon managers in both countries to ensure that the concerns of these stakeholders are addressed, while ensuring acceptable allocations of the harvest. It is these unresolved value judgments, and the lack of effective institutional structures for organizing debate, that present the greatest threat to adaptive harvest management as a viable means for coping with management uncertainty.

RESPONSES TO THIS ARTICLE

Responses to this article are invited. If accepted for publication, your response will be hyperlinked to the article. To submit a comment, follow this link. To read comments already accepted, follow this link.

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