FORUM
Adaptive Management: Promises and Pitfalls

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ABSTRACT / Proponents of the scientific adaptive management approach argue that it increases knowledge acquisition rates, enhances information flow among policy actors, and provides opportunities for creating shared understandings. However, evidence from efforts to implement the approach in New Brunswick, British Columbia, Canada, and the Columbia River Basin indicates that these promises have not been met. The data show that scientific adaptive management relies excessively on the use of linear systems models, discounts nonscientific forms of knowledge, and pays inadequate attention to policy processes that promote the development of shared understandings among diverse stakeholders. To be effective, new adaptive management efforts will need to incorporate knowledge from multiple sources, make use of multiple systems models, and support new forms of cooperation among stakeholders.

[Adaptive management] begins with the central tenet that management involves a continual learning process that cannot conveniently be separated into functions like "research" and "ongoing regulatory activities," and probably never converges to a state of blissful equilibrium involving full knowledge and optimum productivity [Walters 1986, p. 8].

Need for an Adaptive Approach to Ecosystem Management

Adaptive management appeals to scientists and policy makers concerned with making wise choices about the treatment of large-scale ecological systems, ranging from landscapes to river basins (Cortner and Moote 1994). Complex interactions occur at this larger scale, involving both biophysical and social processes. The uncertainty created by complex interactions in large systems of relationships has limited the usefulness of analysis associated with normal hypothesis testing. Faced with such uncertainty, scientists and managers have advocated policies that encourage the development of flexible institutions capable of monitoring, evaluating, and taking corrective actions. Such adaptive management has offered a promising approach for incorporating feedback from models stimulating the interactions of biophysical and social systems (Lee and others 1992, Turner 1994).

KEY WORDS: Adaptive management; Landscape management; Social learning; Natural resource policy; Policy implementation; Systems modeling

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The adaptive management concept has been applied to environmental management situations for nearly 20 years, yet few of these efforts have been studied systematically to see how adaptive management theory holds up in practice. In this paper we compare three examples of adaptive management to demonstrate that the approach suffers from major flaws in its assumptions about how environmental management decisions are made and implemented. We first discuss the rationale for the use of the scientific approach to adaptive management. Drawing upon social learning theory, we identify three elements—rapid knowledge acquisition, effective information flow, and processes for creating shared understandings—that facilitate adaptive learning in human management systems. We then examine three cases where scientific adaptive management principles have been applied to see whether these elements were present or absent and how their presence or absence contributed to the effectiveness of the approach. We conclude that efforts to apply adaptive management techniques have suffered because these elements were not adequately addressed. We also conclude that the scientific adaptive management approach suffers from an overreliance on rational comprehensive planning models, a tendency to discount nonscientific forms of knowledge, and an inattention to policy processes that promote the development of shared understandings among diverse stakeholders.

Scientific Adaptive Management: What Is It?

The term "adaptive management" means different things to different people. Halbert's (1993, p 268) study of the application of adaptive management to Washington State's Timber, Fish, and Wildlife Agreement indicates that to timberland managers, adaptive management "translates to developing predictive tools that can be used for site-specific management." Policy makers, by contrast, tend to perceive adaptive management as something that allows one to see the broad impact of policies and thus emphasize the need to develop large-scale models (Halbert 1993). Scientists, on the other hand, generally adhere to the meaning of adaptive management first articulated by Holling (1978) and Walters (1986). Halbert (1993, p 262) summarizes this interpretation as the application of "experimentation to the design and implementation of natural-resource and environmental management policies." Given the key role that scientists have played in federal land management debates thus far, it is likely that this scientific notion of adaptive management will shape the content and structure of future management interventions on federal lands. We thus restrict the following critique of adaptive management efforts to this version.

The term "adaptive management" first appeared in the natural resources management literature in the mid-1970s (Holling 1978). The approach borrows heavily from adaptive control process theory, which addresses the question of how to construct decision-making devices, or control devices, capable of learning from experience (Bellman 1961). Adaptive control devices have feedback mechanisms that either allow information to accumulate automatically or deliberately probe the environment to gather new information (Bellman 1961). Because these devices can modify their behavior in response to new information, they are better suited to conditions of uncertainty than nonadaptive control devices (Bellman 1961). Similarly, adaptive management incorporates informational feedback loops into the management process in order to accelerate the rate at which environmental decision makers learn from experience.

The scientific adaptive management approach also borrows heavily from operations research and management science (OR/MS). OR/MS relies on the systematic use of the scientific method and mathematical models to help decision makers make choices when faced with decision environments characterized by complexity, shifting conditions, and uncertainty about key relationships among system components (Haley 1990, Thierauf and Klekamp 1975, Keen and Morton 1978). OR/MS is designed to help decision makers make informed choices under conditions where scientific experiments to increase knowledge are too costly, impractical, or too risky to carry out (Haley 1990).

Key Elements for Adaptive Learning

Scientific adaptive management is premised on the notion that managers should structure interventions in ways that permit them to anticipate or take advantage of surprise as a tool for learning, rather than attempting to avoid or merely react to the inevitable surprises that arise (Timmerman 1986). Ethnographic evidence indicates that humans have long used ad-hoc hypothesis testing as a means to take advantage of surprise and increase knowledge acquisition rates (Chandler 1990). Surprises generated through ad-hoc hypothesis testing disrupt the cultural filters through which people view the world and enable them to change their understandings of how the world works (Buck 1989, Chandler 1990). Kuhn (1970) posits that the rapid advancement of technological knowledge during the last two centuries is due to the use of the scientific method of inquiry, a method that increases opportunities for surprise through the systematic and explicit use of an iterative process of hypothesis testing. Platt (1964) argues that the use of "strong inference," or setting up experiments in ways that permit the falsification of hypotheses is an especially effective way to acquire knowledge more rapidly because it enables one to quickly reject hypotheses that do not fit with observed reality and then move on to new hypotheses. Theories about social learning thus suggest that the use of hypothesis testing increases the rate at which individuals and organizations acquire knowledge.

Under conditions of uncertainty, effective management requires that societies do more than merely acquire knowledge: they must also change their behavior in response to new understandings about how the world operates. The ability of institutions to respond to new knowledge depends on whether they have access to new information and whether they have the will and capacity to act on that information. Access to new information is a function of how well information flows within institutions, among institutions, and between institutions and their environment (Craik 1972, Uwadia 1990). McGovern and others (1988) have shown that information flow pathologies, or breakdowns in the processes and structures by which institutions acquire and act upon information, substantially decrease the capacity of institutions to modify their response to new knowledge.

The will and capacity to act on knowledge is also an important element in behavioral change. In many cases, developing the will and capacity for individuals and organizations to adopt environmentally sound management behavior requires that they be convinced that it is in their best interest to engage in long-term, collective action that maintains or improves the system's overall integrity and productivity (Dale 1991, Fox 1991). This task is particularly difficult when the management context is characterized by the presence of a large number of relatively autonomous stakeholders with different values and differential access to power and resources (Dale 1991, Fox 1991). Firey's (1960) work on resource conservation in the Great Plains indicates that the key to such sustained collective action is the creation of willing conformity. Willing conformity occurs when people internalize community norms and values to the point where they act in accordance with those values at the expense of their own self-interest without the presence of coercion (Firey 1960). In situations where a multiplicity of stakeholders are present, the key is not to try to reach consensus on all values and meanings but to create some common values and shared meanings through processes that promote the development of mutual recognition of the legitimacy of the interests of others (Shannon 1987, Moore 1994). Creating these common values requires strengthening social interaction processes that speed up social learning (Korten 1982). Korten's studies of social transformation indicate that social learning is enhanced when societies have institutions capable of "... effectively engaging the necessary participation of system members in contributing to the collective knowledge of the system and in generating policy choices ..." (Korten 1981, p. 613).

Adaptive Management: Its Promises

In the 1970s a group of scientists working at the University of British Columbia developed the adaptive management approach to help environmental decision makers and managers increase knowledge acquisition rates, facilitate information flow among policy actors, and create shared understandings among scientists, policy makers, and managers (Holling 1978, Clark and others 1979, Peterman 1977). Adaptive management relies upon teams of scientists, managers, and policy makers to jointly identify and bound management problems in quantifiable terms (Holling 1978, Walters 1986). The team develops a model to simulate key relationships among the components of the system being managed. This model is used to test a range of hypotheses and identify those policy options most likely to achieve management objectives. Once policy options have been selected and implemented, a monitoring and evaluation system is established so that managers can determine how actual performance compares with expected outcomes. In theory, the use of an explicit iterative hypothesis testing process combined with a systematic monitoring and evaluation process permits managers to accumulate knowledge about the system more rapidly (Holling 1978, Walters 1986). Information flow is facilitated, and shared understandings are created through the use of interdisciplinary teams and through encouraging three categories of policy actors (scientists, managers, and policy makers) to participate in developing the system models used in the hypothesis testing process.

Adaptive Management in Practice: Three Case Studies

In the following section we examine three cases of adaptive management to determine how successful these measures were at increasing knowledge acquisition, facilitating information flow, and promoting shared understandings among stakeholders. The cases include a spruce budworm management effort in New Brunswick, Canada, fisheries management in British Columbia, Canada, and hydro-electric power and fisheries management in the Columbia River Basin, United States. The cases were selected for two reasons: (1) At the time of the study, they were virtually the only cases of adaptive management where documentation on both natural and social issues associated with their use was available,[1] and (2) the three efforts were initiated approximately five years apart over a 15-year period, and thus offer interesting insights into the evolution of adaptive management thinking and practice. The data for this study were drawn primarily from journal articles and project documents. Information about the models used in the Columbia River Basin management effort was obtained through telephone interviews with systems analysts on the Northwest Power Planning Council staff.

Spruce Budworm Management (Eastern Canada)

The adaptive management approach was adopted by the New Brunswick Department of Natural Resources in the early 1970s in response to a spruce budworm epidemic that threatened to devastate tree species of prime importance to the pulp industry, a pillar of the province's economy (Holling 1978). Since the 1950s, provincial and private forest managers had relied on chemical sprays to keep the budworm under control (Kettela 1975). By the late 1960s opposition to spraying surfaced among environmentalists (May 1978) and

[1]Early adaptive management models, which are essentially systems models, differ from models such as FORPLAN in that the adaptive management models explicitly call for close collaboration between systems modelers, policy makers, and managers in their initial construction and subsequent modifications.

some foresters (Rayner and Peerla 1987). Environmentalists questioned the use of sprays on health grounds, while foresters questioned their efficacity as an insect control mechanism.

In 1972, the Canadian government hired a team to develop and implement a model that would increase understanding of budworm population dynamics and thus permit the identification of alternatives to massive spraying campaigns (Holling 1978).[2] Scientists and managers from the Canadian Forest Service and the New Brunswick Department of Natural Resources and scientists from the University of British Columbia and the International Institute for Applied Systems Analysis took part in developing the model. The developers of the budworm model attempted to simulate the interaction of the budworm's system with people and the environment. Five variables were included in the model: host tree, two foliage conditions, the budworm itself, and the weather. Human factors, such as social responses or cultural values, were not incorporated into the model. In the implementation stage, politicians, administrators, and businessmen participated in refining the model and selecting policy alternatives.

The New Brunswick government appointed the Task Force for the Evaluation of Budworm Control Alternatives to identify alternatives to the prevailing policy of total eradication (Baskerville 1978). The task force was headed by a forester from the Federal Department of Environment (Clark and others 1979). This forester eventually played a key role in getting the model transferred and implemented into the federal and provincial forest policy-making process. The task force used the budworm models to identify two major options to the existing policy—early low-dose spraying and a change in harvesting regimes (Cuff and Walker 1984). The task force selected the spraying option on the grounds that a change in harvesting regimes would have jeopardized the pulp industry's supply of pulpwood (Rayner and Peerla 1987). A committee was then appointed by the task force to coordinate monitoring and evaluation efforts for province-wide experiment with different spraying regimes (Canadian Forestry Service 1976).

Implementation of the low-dose spraying policy raised a storm of controversy among environmentalists and some foresters. Environmentalists accused the government of failing to adequately assess the ecological dangers of spraying and complained that the monitoring and evaluation effort was ineffective and biased in favor of spraying interests (May 1978). Environmentalists also felt shut out of the statutory pesticide use decision-making process, which was highly centralized (Miller and Cuff 1986, Miller 1993b). Some forestry scientists were also highly critical of the systems analysis approach, which they felt tended to favor one set of assumptions about how the world functions:

> I believe that it was the Task Force's [Task Force for the Review of CFS Research on the Eastern Spruce Budworm] emphasis on simulation models, the overly-optimistic view of the potential of comprehensive modelling, and power struggles initiated by the appearance of giving organizational approval to one scientific idea in each field covered by model processes that led to progress being made only in directions other than those anticipated by the Task Force report [Cuff and Walker 1984, p. 459].

Adaptive management proponents in New Brunswick had greatly underestimated the complexity of decision-making processes. The modeling team had assumed that decisions were made and implemented by one overarching decision maker: the Canadian government. In fact, many other stakeholders also influenced budworm management decisions through less formal mechanisms (May 1978, Brett-Crowther 1981, Rayner and Peerla 1987). In addition, modeling and implementation processes were structured in ways that permitted the values and intellectual styles of resource professionals to dominate (Miller 1985). Studies by Miller (1985, 1993a,b) indicate that the value orientation and intellectual style of resource professionals involved in the budworm controversy differed substantially from that of most environmentalists. Miller found that resource professionals involved in the dispute tended to take a rational–reductionist approach to solving the problem, which they defined as primarily an issue of insect control (Miller 1985, 1993a). In contrast, environmentalists tended to define the problem as a resource allocation issue and framed solutions in terms of political and social change that would shift forest management away from its pulp production orientation (Miller 1985, 1993a). By the mid-1980s, the complex simulation models had been replaced by a much simpler "tree" model that the provincial forestry department and industry managers found more useful and less controversial (Cuff and Walker 1984).

Fisheries Management (British Columbia)

The adaptive management approach used in New Brunswick was first applied to British Columbia's fisheries management sector in 1974 (Hilborn and others 1984). Adaptive management proponents in British Co-

[2]Details about the building and implementation of the spruce budworm models are drawn from the following sources: Holling (1978); Cuff and Baskerville (1983); Peterman (1977); and Clark and others (1979).

lumbia wished to use the approach to respond to several threats to salmon populations: long-term declines in the number of salmon caught and produced, expanded reliance on hatcheries, and potential damages to salmon spawning and rearing habitat from proposed hydroelectric facilities.[3]

Adaptive management efforts in British Columbia also relied upon a process of model development, hypothesis testing, and experimentation with different management options. The modeling team developed simulation models for the Fisheries and Marine Service in the Canadian Department of Fisheries and Environment, and the British Columbia Fish and Wildlife Branch (Holling 1978). As in the spruce budworm case, the modeling team emphasized interdisciplinary communication among team members and invited scientists and managers working for its client agencies to participate in the development of simulation models. The British Columbia fisheries models were much more complex than the spruce budworm models, in that their assumptions incorporated economic and biophysical factors, rather than only biophysical factors.

As a result of their experience in New Brunswick, the modeling team incorporated more sophisticated assumptions about how implementable decisions are made into their models. Rather than assuming a value-free decision-making process in which government fish managers were free to make the decisions they wished, the modelers attempted to quantify and incorporate objectives from various interest groups into the models (Keeney 1977, Hilborn and Walters 1977, Holling 1978, Sheehan and Russell 1978). The modeling team developed utility functions to help decision makers make trade-offs among competing objectives (Holling 1978). The team eventually concluded that utility functions were not useful for ranking policies (Holling 1978, Hilborn and Walters 1977), but they noted that the process of forcing managers and interest groups to quantify their objectives was useful as it provided a forum for diverse groups to discuss conflicting objectives (Hilborn and Walters 1977).

The simulation models also were useful in helping scientists identify misguided policies. For example, one set of simulations showed that enhancement without a decline in allowable catch in its early years would decimate less productive wild stocks (Walters 1986). These findings suggested the need to adopt a low allowable catch quota policy so the wild stocks could recover (Walters 1986). Another set of simulations indicated that the sport fishery accounted for nearly twice as many salmon caught as had previously been thought, suggesting the need for greater regulation of the previously unregulated sport fishery (Walters and Riddell 1986, Hilborn 1979, Hilborn and others 1984).

However, attempts to apply the models and the iterative hypothesis testing approach to real management situations had mixed results. The following examples of attempts to implement policies based on findings from the simulation models illustrate some of the difficulties of operationalizing the adaptive management approach.

Salmon enhancement facilities planning.[4] Efforts to apply the adaptive management approach to enhancement facilities planning during the late 1970s were completely unsuccessful (Hilborn 1979). The idea of an enhancement planning model originated with the modeling team, who felt that it could be used to determine how many years of monitoring it would take to tell whether an enhancement facility was producing more fish. The model was completed in a three-day workshop with biologists and economists in the federal fisheries department. However, the model was never accepted by the fisheries department staff, who felt that the model was not useful. Opposition to the model came primarily from the engineering staff, who complained that monitoring costs would be too high. Staff engineers were also unwilling to risk the possibility that the adaptive management approach would show their facilities to be unsuccessful at producing fish.

Sports fishery regulations.[5] The team had only slightly better results with policies derived from a sport fishery model developed for the federal fisheries department. In 1977, a key fisheries biologist asked the team to help the department develop a model for analyzing marine sport salmon fishery regulatory options (Hilborn 1979). The team worked closely with the fisheries staff to develop the model, and in 1978 the fisheries department adopted the model as its primary policy evaluation tool.

Attempts to develop regulations based on the findings of the sport fishery model created a huge outcry among sport fishery advocates. When the fisheries department used the sport fishery modeling results to jus-

[3]Details about the British Columbia experiments with adaptive management were drawn from writings by Holling (1978); Hilborn (1979, 1987); and Walters (1986).

[4]Information on the salmon enhancement model was drawn from Hilborn (1979).

[5]Information on the application of the sport fishery models was drawn from Hilborn (1979); Hilborn and others (1984); Holling (1978); and Walters and Riddell (1986).

tify a proposal to prohibit the keeping of salmon less than 20 inches long, violent opposition from the sport fishery lobby stopped the regulation before it could be implemented. After running more simulations, the fisheries department then proposed that a seasonal catch limit be put into effect. The sport fish advisory committee accepted this rule, primarily because sport fishers rarely caught more fish than allowed under the proposed regulations. In 1980, biologists working with the model concluded that stricter regulations would double chinook escapements. Once again, the sport fishing lobby objected to the new rules and pressured the fisheries department to include the sport fish advisory committee in the policy selection process. This committee rejected the alternatives derived from the computer model and submitted a compromise based on the intuition and experience of its constituents. The fisheries department eventually accepted the compromise proposal (Hilborn and others 1984) despite objections from fish biologists.

In 1982 a new version of the sport fishery model was once again used to justify stricter fishing regulations, sparking another round of protests and violence by fishing interests (Pinkerton 1989). Over the next decade public participation in the fisheries management process expanded, but fisheries management in British Columbia is still dominated by the federal fisheries bureaucracy (Dale 1991). Attempts to apply the adaptive management approach have been hampered by the inability of provincial fish managers to change regulations without prior approval from the central government and by the difficulty of coordinating a monitoring effort among autonomous, decentralized user groups (Hilborn and Luedke 1987).

Balancing Power and Fish (Columbia River Basin)

The adaptive management approach was adopted in the Columbia River Basin in 1984 (Lee 1989). In the Canadian cases discussed above, the formal decision-making process was relatively simple. Decision-making authority was vested in one provincial government, with oversight by one federal agency. In contrast, in the Columbia River Basin statutory decision-making authority has always been divided among a complex set of relatively autonomous actors, including four states, a number of Indian tribes, and several federal agencies (Lee 1989, NWPPC 1982, 1984). A host of other stakeholders, including utility companies, industrial power users, residential power users, and a variety of recreational and environmentalist organizations also influence policy decisions (Lee 1989).

In 1980, the US Congress passed the Northwest Power Planning and Conservation Act (PL 96-501) to establish an institutional framework for coordinating Columbia River Basin management (Lee and Lawrence 1986, NWPPC 1982). The act created the Northwest Power Planning Council (NWPPC), composed of eight gubernatorial appointees (two each from the states of Idaho, Montana, Oregon, and Washington). The council was given a mandate to manage the Columbia River Basin system using the best scientific information available and through facilitating cooperation among the system's stakeholders (Public Law 96-501 1980).

As in New Brunswick and British Columbia, systems models played a key role in the Columbia River Basin. Initially, the council relied solely upon models developed by the Bonneville Power Authority (BPA) and the Army Corps of Engineers (AFL Memo 1986). However, the fish agencies and tribal authorities were quick to object to the council's reliance on these models. Objections centered on two points (AFL Memo 1986). First, both the fish agencies and the tribes felt that the models' assumptions were flawed in favor of the hydropower interests and that, therefore, the recommendations did not adequately represent fish interests. Second, both groups felt that only analyses favorable to the Bonneville Power Authority had been conducted and reported. The following comment on the BPA's proposal to establish an intertie agreement for exporting electricity to California reflects the feelings of the fisheries and tribal representatives about the reliability of these models:

> The DEIS' [draft environmental impact statement] analysis of impacts on salmon and steelhead suffers from a number of fatal defects. Most of these relate to the use of the FISHPASS computer model to quantify impacts on salmon and steelhead in purportedly numerically precise terms. Bonneville has failed to disclose and incorporate the great uncertainty of its approach to quantifying fisheries impacts. Moreover, Bonneville has adopted convenient assumptions that mask likely effects. Those effects that are found are obscured by a confusing format for presentation and false premises regarding significance [AFL Memo 1987, p. 4].

In response to this criticism, the council worked to build a decision-making process that would allow a wider range of stakeholders to play a significant role in policy development and implementation. A new model has been developed through a collaborative process between utility and environmental interests, and groups who disagree with the models' assumptions can petition the council to modify the models (P. Swartz personal communication 1993). The council sends copies of the models to groups interested in running their own simulations and provides staff support for groups who wish to run their own simulations but lack the hardware to use the models themselves (P. Swartz personal communication 1993).

Views on the part of policy analysts working for the council have also shifted over time. As in the British Columbia fisheries case, analysts initially tried to develop optimization techniques that would permit the council to select the "best" options. However, like their Canadian counterparts, the analysts discovered that the power planning problem was too complex for optimization procedures. Consequently, they switched to using the models primarily to frame alternatives and compare different scenarios (P. Swartz, personal communication 1993).

Because the council is required by law to make decisions on the basis of the "best scientific knowledge" available, scientific information has become a key weapon in the political struggles over how to manage the Columbia River Basin. Stakeholders who have the capacity to produce and analyze scientific data are in a much more powerful position than those who do not. A "model war" has broken out as the various stakeholders compete to produce the "best" science (C. McConnaha personal communication 1993). Three models are now used to analyze salmon life cycles and fish passage questions: the council's model, the University of Washington's Columbia River salmon passage (CRiSP) model, and a model built recently by the fishery agencies and the tribes (C. McConnaha personel communication 1993). The key assumptions of the council model and the fishery model are quite close, and in general the Northwest Power Planning Council defers to the fishery model when the models yield different results. In contrast, the CRiSP model's assumptions differ substantially from the other two models in that it assigns a much higher benefit value to the transport of salmon, and a much lower value to the benefits of changing flow patterns. As a result, given the same input, the CRiSP model's results show that modifications of main-stem passage flows are less beneficial than results from either the fishery or council model would indicate.

The council has demonstrated a commitment to a process that encourages stakeholder input, as evidenced by the manner in which it has structured the Columbia River Basin system planning effort (NWPPC 1987). System-wide planning is directed by the System Planning Group composed of representatives from state and federal fishery agencies and the tribes (NWPPC 1987). Federal land management agencies, energy agencies, private utility commissions, the Army Corps of Engineers, and the Bureau of Reclamation have the option of sending representatives to the planning group. Subbasin planning teams are structured along similar lines. The council's Monitoring and Evaluation Group coordinates standardized data collection among the different groups to eliminate inconsistencies in the technical data used in policy analysis. To ensure that a full range of interests is incorporated into the policy analysis process, the council requires that the System Planning Group and the Monitoring and Evaluation Group coordinate in the analysis and evaluation of management options.

It is unclear whether or not the adaptive management approach used in the Columbia River Basin works. The first major experiments in the fisheries sector, the Yakima and Klickitat hatcheries, have yet to be completed, and results of the experiments will not be available for many years (Clune and Dauble 1991). Assessments of the Columbia River Basin management effort have noted five key barriers to the use of an experimental approach to planning: (1) substantial investments in monitoring and evaluation (Volkmann and McConnaha 1992, Lee 1991b, 1993); (2) the difficulty of reconciling centralized coordination with decentralized implementation (Lee 1991a, 1993); (3) the discrepancy between the long planning horizons needed for an experimental approach and the short tenure for council members (AFL Memo 1990); (4) feelings on the part of the fisheries agencies, tribes, and environmental organizations that the council defers to hydropower interests when difficult trade-offs have to be made (Blumm 1987, AFL Memo 1990); and (5) the unwillingness of state and federal resource managers to risk the political consequences of experiment failure (Volkmann and McConnaha 1992, Lee 1991a, 1993).

Pitfalls of Scientific Adaptive Management

Does the empirical evidence indicate that scientific adaptive management enhances social learning about ecological relationships? Does scientific adaptive management provide what it promises in terms of increasing the rate at which policy makers and resource manages acquire knowledge about ecological relationships, facilitating information flows among policy actors, and creating shared understandings among policy actors? Evidence from the three case studies presented above suggests that it falls short of its promises in all three areas.

Increasing Knowledge Acquisition Rates

In all three cases, adaptive management proponents relied upon the use of systems models and an iterative hypothesis testing process to enhance knowledge acquisition rates. The use of these models has been highly controversial in all three cases. In large part, controversy has centered around the underlying assumption that planning is an objective process and that scientists and bureaucrats are neutral policy actors. The cases indicate that scientists frequently disagree on the "facts," and thus disagree about the assumptions on which the systems should be structured. Policy makers are equally divided as to which community preferences should be incorporated into the decision structure of the models.

The use of systems models exacerbates this problem because of their requirements for quantifiable data. Such models stress the importance of objectives that are amenable to quantification while deemphasizing the importance of nonquantifiable objectives (Mintzberg 1980). The New Brunswick case study clearly illustrates the dangers inherent in this approach: the government foresters consistently framed their solutions to the budworm epidemic in technical terms and ignored the fact that the problem was largely a question of differences in perceptions as to what the role of forests in New Brunswick should be (Miller 1985, 1993a). The models enabled the forestry department to increase its knowledge about spruce budworm dynamics but did little to increase the department's knowledge of the values and objectives of key stakeholders.

The case studies indicate that the systems model approach is also limited by its implicit assumption that scientific knowledge is more valid for making resource management decisions than other kinds of knowledge. The corollary to this assumption is that the more managers rely on scientific knowledge in making decisions, the better their decisions will be. However, a great many problems of managing ecosystem relationships are "wicked" problems (Allen and Gould 1986), caused by disagreements about how the ecosystem ought to be managed, rather than about the technical merits of particular management interventions. While the systems models used in New Brunswick, British Columbia, and the Columbia River Basin were able to resolve some questions about the technical advisability of specific management interventions, the modelers discovered that they could not be used to choose between two technically feasible options with very different resource allocation implications.

The iterative hypothesis testing process has also been difficult to implement. In all three cases, the monitoring and evaluation effort needed to carry out this process has proved costly and controversial. Monitoring and evaluation was especially controversial in New Brunswick where one stakeholder was responsible for monitoring and evaluating the results of spraying experiments. The Northwest Power Planning Council has attempted to avert such controversy by giving major stakeholders the possibility of participating in monitoring and evaluation efforts. The costs of this kind of involvement, however, are enormous, and it is questionable whether such investments can be sustained in the long run (J. M. Volkmann personal communication 1992). The unwillingness of resource managers to risk failure has also inhibited the use of the hypothesis testing approach in both British Columbia and the Columbia River Basin (Lee 1991a, Hilborn 1979).

Enhancing Information Flow

In the three cases described above, the scientific adaptive management approach relied upon the use of interdisciplinary teams of scientists working closely with resource managers and policy makers to ensure that the information produced was readily transferred to decision makers and policy implementers. However, the approach was flawed by the modelers' narrow conception about who constituted decision makers and implementers. In New Brunswick, for example, the modeling team assumed that federal and provincial foresters and politicians were the key actors and marginalized representatives of the environmental movement from the model development process. This proved to be a costly mistake, as the environmentalists mounted a formidable protest when the forestry department began implementing the new spraying policy. The New Brunswick case also illustrates the danger of relying on one powerful stakeholder to handle monitoring and evaluation: the temptation to hide information unfavorable to the data keeper's interests is very strong.

Information flow in the British Columbian case was less restricted, but still limited largely to exchanges among scientists and federal and provincial fisheries staff. The controversy over the size limitation for the sport fishery, for example, could probably have been avoided if closer communication links had existed between the sport fish advisory committee and the modeling team. On a more positive note, explicit attempts to incorporate several user groups into the development of utility functions for the Skeena River salmon fishery models were helpful in getting user groups to share information about differing values, goals, and objectives. In its early stages, the Columbia River Basin management effort also suffered from information blockages when it discounted or ignored information produced by the fish agencies and tribes. However, the Northwest Power Planning Council has since demonstrated its willingness to try to reduce information flow barriers by opening up the modeling process and by actively soliciting the involvement of all major stakeholders in monitoring and evaluation efforts. Thus, the evidence from the British Columbia and Columbia River Basin case studies suggests that adaptive management models can be useful tools for enhancing information flow through stimulation of discussion among stakeholders about values, goals, objectives, and acceptable management options.

Creating Shared Understandings

The case studies also demonstrate that the scientific adaptive management approach has failed to provide adequate forums for the creation of shared understandings among stakeholders. The lack of such forums was particularly problematic in New Brunswick, where one of the key stakeholders attempted to monopolize both information and decision-making authority. The resultant outcry on the part of excluded stakeholders greatly impeded the provincial forestry department's attempts to implement new policies. The lessons from New Brunswick prompted adaptive management proponents in British Columbia to conduct workshops where representatives of interest groups could discuss their value differences and, it was hoped, arrive at mutually acceptable solutions. However, the violence and persistence of the sport fishery controversies during the 1980s indicate that these forums were relatively ineffective at resolving conflicts over resource allocations.

Efforts to develop forums for creating shared understandings were much more sophisticated in the Columbia River Basin case. The Northwest Power Planning Council has adopted the twin policies of making information readily available and of opening up the analysis process for very pragmatic reasons: if stakeholders disagree on the structure of the models used to identify alternative scenarios, conflicts over management recommendations will remain unresolvable (P. Swartz personal communication 1993). If stakeholders can at least agree on some basic assumptions, there is room for them to begin negotiating for mutually acceptable compromises. Policy selection itself occurs through a political process of public hearings and commentary, with decision-making authority vested in the council (I. Bottinger personal communication 1992). It is too early to know whether the adaptive management approach adopted by the Northwest Power Planning Council, with its reliance on systems models, iterative hypothesis testing, and consensus building, will prove effective in the long run. However, the council's concern with developing institutional structures and processes that provide greater opportunity for stakeholder participation in making and implementing decisions is a step forward in addressing the real issue of sustainable management: how to foster the sense of collective responsibility that is needed to convince relatively autonomous stakeholders to engage in long-term, collective action.

Conclusion

Given the limitations of scientific adaptive management, it is unlikely that a wholesale and uncritical adoption of the approach will contribute to the management of landscapes characterized by complex relations between organisms, environment, and human societies. Nonetheless, the approach does have certain positive aspects that warrant being incorporated into a broader philosophy of adaptive management. In assessing these strengths, we will look at three elements of the approach: its tools (systems models), its method of inquiry (iterative hypothesis testing), and the social structures and processes that should organize its use.

Systems models can facilitate iterative learning about the components of ecological systems and relationships that are important at scales ranging from sites to landscapes to regions. In the British Columbia case study, for example, simulation models helped managers realize that the recreational fishery had a much larger impact on salmon populations than had previously been thought. Moreover, the ability to run a wide variety of scenarios rather quickly gives policy makers the opportunity to try out alternatives that they might otherwise never consider.

In the three case studies examined in this report, the modelers all eventually concluded the most useful function of the models was their ability to allow users an opportunity to explore different "what if" scenarios. As long as users recognize that the model's outcomes are constrained by its basic assumptions and that its conclusions therefore represent only one view of reality (and thus only a fraction of the possible alternatives), the exercise can be highly instructive. Seen in this light, the trend toward the development of competing models in the Columbia River Basin is a significant step toward collaborative learning (Walker and Daniels 1994). The resulting debates over the merits of the different models will help identify how the underlying assumptions may affect possible outcomes. With only one model, based on one set of assumptions, assumptions and values of less powerful stakeholders are bound to be submerged. The presence of multiple models with their multiple perspectives will encourage decision makers to return to the political arena as the appropriate forum for debating how social and cultural values affect both discovery of consequences and choice of corrective action.

The rapid technological changes that have occurred during the last 200 years bear ample witness to the power of the iterative hypothesis testing method of inquiry. Its usefulness in helping people solve ecological problems is further evidenced by the widespread use of protoscience, its less formal cousin, in less technologically advanced societies (Chandler 1990). As with the systems models, as long as the method's limitations are kept firmly in mind, iterative hypothesis testing can help improve management decisions. In his critique of the application of systems analysis to policy making, Mintzberg (1980, p 124) notes that the danger of relying solely on intuition is that "intuition often suffers from tunnel vision, from being unable to break out of the patterns of the past to recognize a situation as new." Use of the hypothesis testing method can thus help managers become aware of the limitations of the old patterns and allow them to perceive new patterns that they had previously ignored.

The adaptive management concept stresses the importance of social interaction and consensus building in reaching management decisions. However, with the exception of the Columbia River Basin materials, the adaptive management literature pays little attention to the question of what types of institutional structures and processes are required for the approach to work on a large-scale basis. The importance for institutions to be flexible, willing to take risks, and incorporate a variety of perspectives into the decision-making process was highlighted in both the New Brunswick and British Columbia cases. However, other than emphasizing the need for interdisciplinary workshops and for close contacts between modelers, scientists, and policy makers, the people involved with these case studies provide very few pointers as to the means by which one might create or foster the institutional conditions needed for adaptive management.

Fortunately, the Columbia River Basin materials provide a richer and more thoughtful perspective on the kinds of institutional structures and processes needed to make adaptive management work. Essentially the problem is one of creating an institutional framework that promotes the coordination of management activities undertaken by many loosely connected, but interdependent, institutions (K. N. Lee 1991a, R. G. Lee 1992, Dryzek 1987). Despite limitations, the institutional innovations in the Columbia River Basin provide a model that is worth building upon. The institutional innovation was relatively simple in terms of its structure: the creation of a "neutral" institution that would be responsible for making system-wide decisions, and for coordinating the activities of the basin's multiplicity of stakeholders. In terms of process, the innovation was quite complex: the establishment of a variety of processes, including public hearings, public meetings, interest group meetings, and round-tables, that facilitate ongoing dialogue between the council and stakeholders and among the various stakeholders. In essence, the Columbia River Basin case suggests that adaptive management may be evolving from its original preoccupation with creating better optimization models toward a new concern for developing the institutions needed to support experimentally driven management. Questions can be raised about whether the institutional structures of the stakeholder bureaucracies provide the flexibility needed for adaptive management, questions can be raised about the contradictions between the short terms of office and the long-term nature of adaptive management experiments, and questions can be raised about the ability to have a neutral council when it receives its funding from a few key stakeholders. These questions are valid and need to be addressed in future research. However, they should not obscure the promise that such institutional innovations offer for advancing our ability to manage ecological relationships at the scale of large landscapes (Lee and others 1992).

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