Adaptive Management of Renewable Resources

An overview of an IIASA book
written by Carl Walters
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FOREWORD

This Executive Report reviews the book ***Adaptive Management of Renewable Resources*** by Professor Carl Walters. I hazard a prediction. It will become a classic for the science and management of renewable resources. As such it will stand with the earlier classics in the field – Beverton and Holt's (1957) "On the dynamics of exploited fish populations", Ricker's (1958) "Handbook of computations for biological statistics of fish populations", and Ivlev's (1961) ***Experimental Ecology of the Feeding Fish***. All these concern fisheries ecology, economics, and management. In the field of fisheries, basic empirical and theoretical science, mathematics, and hard management practice have been combined more effectively than for any other renewable resource. Professor Walters extends that base into examples that cover a full range of living resources – forests, wildlife, and range resources.

One could call this a book in applied ecology, but that would be wrong. It is basically a book on human behavior and management science. The system that Professor Walters defines is one that includes the fish, the fishermen who harvest them, and the bureaucrats who attempt to monitor and manage both. As a consequence, its central theme is on human learning of the laws that determine how a partially observed system functions.

We do not learn from a system that is constant. This is not serious if the system is known, is static, and presents no surprises. But resource systems are exactly the opposite. They are known only very partially, which will always be so; they are dynamic and they produce endless surprises – from the collapse of fisheries to the reemergence of other ecosystems. And the act of management and harvesting changes the fundamental structure of the resource itself. Age structure changes; genetic stocks change; interacting species disappear and new ones emerge; climate and ocean conditions themselves become modified by human actions producing unexpected resource consequences.

The approach Professor Walters presents is rooted in the reality of this change and of the inherent unknowability of the evolving character of the system. Hence management has to be adaptive. And it has to be actively so. In this way management designs become explicit experiments to manipulate systems into regimes of behavior that are most conducive to learning. It combines, therefore, an equal emphasis on producing economic return and social persistence.

This body of work owes much of its character and uniqueness to an important set of conjunctions that occurred in the very early days of the International Institute for Applied Systems Analysis (IIASA). In 1974–75 Professor Walters was Deputy Leader of IIASA's Ecology Project. He found, during the same period, a happy intersection of opportunity. His experience in systems ecology and fisheries management began to move in major new directions opened by Tjalling Koopmans' kind of economics, George Dantzig's optimization studies, and Howard Raiffa's decision theory. It is an example of the power of intersecting the different experiences and strengths of individuals of uniformly outstanding competence.

The book owes its sweep in part to those connections. If that was all, however, it might be of only theoretical interest. But Professor Walters has turned the book into one of profound applied consequence by testing and applying the ideas within the hard reality of resource industries and resource management agencies.

It is that combination of empirical scholarship, of theory and application, that, in my view, will make this book a classic.

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CONTENTS

INTRODUCTION

Renewable natural resources provide important contributions to food, fiber, and recreation in many parts of the world. The economies of some regions are heavily dependent on fisheries and forestry, and consumptive use of wildlife (hunting) is a traditional recreational pastime across Europe and North America. The management of renewable resources usually involves public agencies that are responsible for harvest regulation, and often production enhancement, so as to provide sustainable yields into the long-term future (resource husbandry). The track record of such agencies has been spotty: many resources have been mined to low levels before effective harvest regulation could be developed, while others have been managed so conservatively as to miss major harvesting opportunities.

Three key features of renewable resources have made them difficult to manage. First, sustainable production depends on leaving behind a "capital" stock after each harvesting, and there are definite limits to the production rates that this stock can maintain. Second, harvesting is normally undertaken by a community or industry of harvesters whose activities (investment, searching, etc.) are not completely monitored or regulated, so that dynamic responses, such as overcapitalization of fishing fleets, are common. Third, the biological relationships between managed stock size and production rates arises through a complex interplay between the organisms and their surrounding ecosystem; for any particular population, this relationship cannot be predicted in advance from ecological principles and must, instead, be learned through actual management experience.

2

ADAPTIVE MANAGEMENT AND UNCERTAINTY

Most management agencies maintain monitoring and research activities that are aimed at understanding the stock–production relationship. However, research activities are often not closely integrated with management decision making, and scientists have traditionally recommended conservative harvest policies so as to protect the population until better biological understanding can be accumulated. A fundamental presumption in such recommendations is that the ecological basis for production can be researched on a piecemeal, experimental-components basis, and the results eventually synthesized into an overall understanding of how the resource behaves. However, various attempts to conduct such syntheses, in the form of predictive mathematical models of resource behavior, have not been notably successful; the modeling exercises have revealed large gaps in understanding of various processes that are difficult to study in the field or laboratory, and predictions of optimum stock sizes often involve gross extrapolations beyond the range of recent historical or experimental experience (*Figure 2.1*).

Frustration with the linkage between science and management has led to the concept that management should be viewed as an adaptive process, in which regulatory and enhancement actions are treated as deliberate experiments

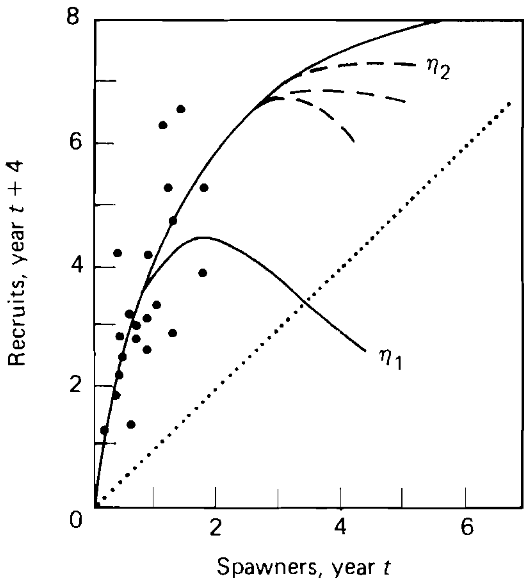

Figure 2.1. Relationship between number of sockeye salmon allowed to spawn in the Fraser River, BC, and number of resulting offspring measured as recruits to the fishery four years later. Data are for 1939–73, omitting every fourth (cycle) year beginning in 1942. The curves η_1 and η_2 are alternative extrapolations of response to increased spawning stock. η_2 predicts higher yields if more fish were allowed to spawn. (*Figure 1.1* in *Adaptive Management of Renewable Resources.*)

with uncertain outcomes. This concept goes far beyond the traditional notion that uncertainties imply risks that should be accounted for through cautious decision making; risky choices are also seen in adaptive management as opportunities to learn more about system potentials, and hence to have positive value in reducing the legacy of uncertainty that will be faced by future decision makers. Basic research is seen not as taking a lead in developing the understanding needed for making predictions, but rather as a means to better understand the response patterns revealed by management (in hindsight) and as an exploratory investment that might uncover new policy instruments and options.

It would be easy enough to design a blind process of trial-and-error management that would be adaptive in the evolutionary sense that major mistakes would tend not to be repeated. But such a process would be unnecessarily wasteful: by analysis of historical experience in relation to ecological theory and constraints, it should be possible to design much more intelligent, directed searches for productive and sustainable harvest policies. Thus, adaptive management is seen as involving three essential tasks. First, it involves structured synthesis and analysis, through attempts to build predictive models, of major processes and uncertainties; the objective here is not to build a single best prediction or to define a single best policy choice, but is instead to identify a strategic range of alternative hypotheses that are consistent with historical experience, but that imply different responses (opportunities for improved harvest) outside the range of that experience. Second, adaptive management involves the use of formal optimization techniques to search for optimum policies that account not only for existing uncertainties, but also for the effects that current decisions will have on the uncertainties that future decision makers will face. (In other words, the adaptive manager attempts to model not only the managed system, but also the data gathering and learning process about that system.) Third, adaptive management involves the design and implementation of improved monitoring programs for detecting system responses more quickly, along with the design of more flexible harvesting industries that can respond to unexpected changes quickly without undue economic or social hardship.

A central controversy in adaptive management concerns the question of whether it is worthwhile to engage in deliberate and perhaps risky experiments involving substantial changes in harvesting rates, thus allowing measurement of production rates across a range of stock sizes. This involves two distinct issues, the first of which is not biological. To conduct variable harvest experiments means either giving up harvests today in favor of possibly higher harvests in the future, or else taking more today while risking losses in the

Table 2.1. Conventional versus adaptive attitudes about the objectives of formal policy analysis (*Table 11.1* in *Adaptive Management of Renewable Resources).*

Conventional		Adaptive	
(1)	Seek precise predictions	(1a)	Uncover range of possibilities
(2)	Build prediction from detailed understanding	(2a)	Predict from experience with aggregate responses
(3)	Promote scientific consensus	(3a)	Embrace alternatives
(4)	Minimize conflict among actors	(4a)	Highlight difficult trade-offs
(5)	Emphasize short-term objectives	(5a)	Promote long-term objectives
(6)	Presume certainty in seeking best action	(6a)	Evaluate future feedback and learning
(7)	Define best action from set of obvious alternatives	(7a)	Seek imaginative new options
(8)	Seek productive equilibrium	(8a)	Expect and profit from change

future if stocks are depleted. This trade-off between present and future values is seldom clear-cut, and there is seldom consensus among management actors (harvesters versus conservationists, etc.) about the best point to aim for in the trade-off; adaptive management is unnecessary or irrelevant in situations where future harvests carry little weight in relation to the present.

Beyond the fundamental issue of values, there is a technical issue that modeling and optimization can help to resolve: this is the issue of passive versus active adaptation. A traditional prescription from model builders has been that one should buiid the best possible predictive model, then act as though this model were correct until evidence to the contrary becomes available. This passively adaptive approach to management can work quite well in contexts where even the nominal best decision would be informative, but it can

Table 2.2 Conventional versus adaptive tactics for policy development and presentation (*Table 11.2* in *Adaptive Management of Renewable Resources*).

Conventional		Adaptive	
(1)	Committee meetings and hearings	(1a)	Structured workshops
(2)	Technical reports and papers	(2a)	Slide shows and computer games
(3)	Detailed facts and figures to back arguments	(3a)	Compressed verbal and visual arguments
(4)	Exhaustive presentation of quantitative options	(4a)	Definition of few strategic alternatives
(5)	Dispassionate view	(5a)	Personal enthusiasm
(6)	Pretense of superior knowledge or insight	(6a)	Invitation to and assistance with alternative assessments

result in managed stocks being locked into unproductive equilibria at far from the best levels (see *Figure 2.1*). A key problem for the adaptive manager is to recognize when such an unproductive and uninformative equilibrium exists or is likely to develop; given that recognition, formal optimization methods can be used to compare passive adaptation with more daring options that involve probing changes in harvest rates.

Policy analysis for adaptive management involves some quite different attitudes than are conventionally held by scientists and analysts in the renewable resources fields (*Table 2.1*). The conventional attitudes (and goals of analysis) have arisen from the presumption that biological uncertainties are small and can be resolved through careful modeling; in such cases it might, indeed, be best to deliberately seek stable and productive equilibrium in resource stocks. The adaptive analysts attitudes given in *Table 2.1* reflect a much more humble, if not pessimistic, viewpoint about the magnitude of uncertainties and the importance of seeking imaginative new ways to deal with these uncertainties. Along with changes in attitudes, policy analysis for adaptive management should involve some changes in tactics for policy development and communication (*Table 2.2*); these changes again reflect a more humble perspective about the need to involve a variety of actors and ideas in policy formulation and decision making. In short, by explicitly revealing uncertainties and difficult choices related to risks and time preferences, the adaptive analyst must discard any cloak of authority that might be fashioned from the conventional trappings (massive reports, charts, etc.) of policy analysis.

3

MODEL BUILDING AND PARAMETERS

Model building for renewable resource management has often been pursued under the assumption that bigger is always better, with the key to successful prediction being more precise and detailed calculations. Adaptive policy design seldom involves very complicated models, for some very good reasons. First, with a bit of careful analysis it is often possible to show that the details simply do not matter, at least in comparison to broader uncertainties about what factors to model in the first place. A good example of this problem occurred with the Peru anchoveta (*Figure 3.1*), the world's largest fishery; advisers to the Peruvian government agonized in great detail over the ecology of the fish and its relation to the El Niño oceanographic phenomenon, but they did not make an effective case for the broader need to regulate the fishing industry so that recovery would be possible if a collapse did occur. Second, with a limited data base and as model complexity increases it becomes progressively more difficult to estimate each model parameter with any statistical precision; on the other hand, sensitivity of the model predictions to each parameter does not necessarily decrease as the number of parameters increases. Third, and perhaps most important, models should be understandable if they are to be of value in stimulating imaginative searches for better policy options and in clarifying possible outcomes in debates that involve actors with conflicting objectives. Particularly in conflict situations, complex models are more likely to create further confusion and distrust, rather than to promote the kind of mutual understanding that is important to cooperative problem solving in the face of uncertainty.

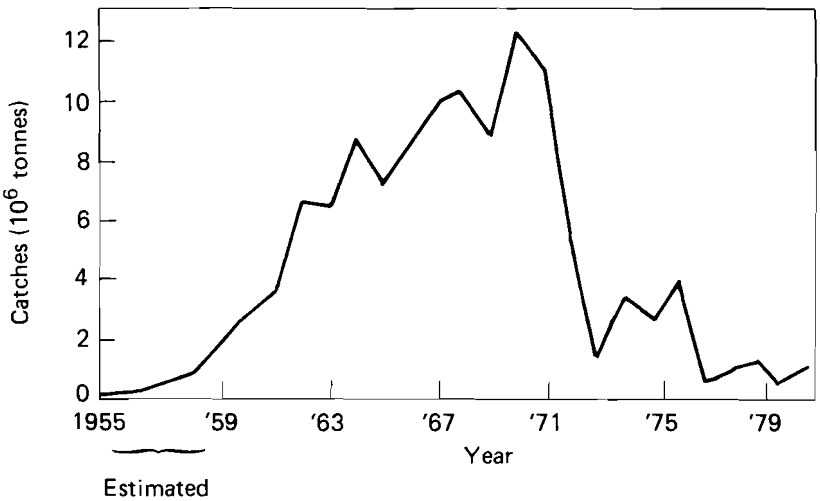

Figure 3.1. Development of the Peruvian anchoveta fishery. The sharp collapse in 1972–73 was apparently associated with a major oceanographic change known as El Niño. (*Figure 2.1* in *Adaptive Management of Renewable Resources.*)

The biological and physical environments for renewable resource production are often changing in time, due both to human influences on ecosystems and to natural "climate" changes on various time scales. Thus, it is unwise to assume constant parameter values for any resource production model and to trust that older historical data and experience are relevant to the prediction of future responses. Further, it is generally not possible to anticipate the parameter changes by using more detailed models that spell out the causes of change; usually, the effects of several possible causes are "confounded" in the historical data so that the correct one(s) cannot be determined with any confidence and, in any case, the correct causal agent is likely to be unpredictable in its behavior. A basic consequence of slow and unpredictable changes in production relationships is that uncertainty about the relationships will grow over time if the system is not disturbed regularly so as to sample a range of stock sizes. This means that management choices

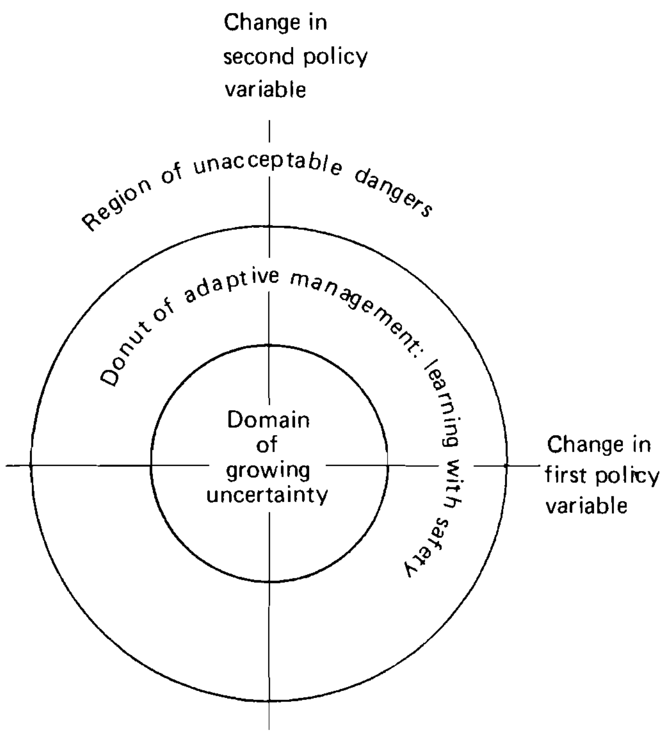

Figure 3.2. Koonce's donut. Changes in policy variables must be reasonably large to allow learning about policy effects, but very large changes imply unacceptable risks. (*Figure 7.6* in *Adaptive Management of Renewable Resources*.)

generate a donut-shaped pattern of possible outcomes regarding uncertainty (*Figure 3.2*). If management policies are held steady and the stock size remains near its historical average, the manager is operating in a donut hole of growing uncertainty. Moderate disturbances and policy changes will result in enough informative variation to stay in a domain of decreasing uncertainty (the donut itself). Large and indefensibly risky disturbances define the outside of the donut. Thus, the donut represents a compromise or balanced level of variation where the manager and the harvesting industry can detect and profit from change; a major challenge for the adaptive manager is to define where this domain lies in terms of the practical policy instruments at his or her disposal and the objectives and constraints defined by the harvesting industry and other actors involved in decision making.

FEEDBACK

Some management agencies attempt to induce informative variation by making small policy changes (tinkering) or by not trying to control stock sizes too precisely so that the effects of random, natural variations (dithering) are not fully dampened through responsive changes in harvest rates. One objective in the development of adaptive management theory has been to determine, by using formal optimization techniques, whether the tinkering approach is, in fact, any better than purely passive adaptation or the more extreme approach of making either large changes or no changes at all. The optimization results available to date all point to the same conclusion, namely that tinkering (and related incremental approaches to management) is *not* a wise approach. Small changes have practically no value in resolving major uncertainties (effects are too small to detect against the background noise caused by other factors), yet cause annoyance (or even severe hardship) for the harvesting industry. In terms of harvest rate variation, long-term harvests are likely to be maximized by following either a passive adaptive approach (no deliberate changes) or else making large and very informative experimental changes (*Figure 4.1*). In short, tinkering is not a good compromise when faced with a hard choice between doing nothing (living with uncertainty) and doing a really substantial experiment.

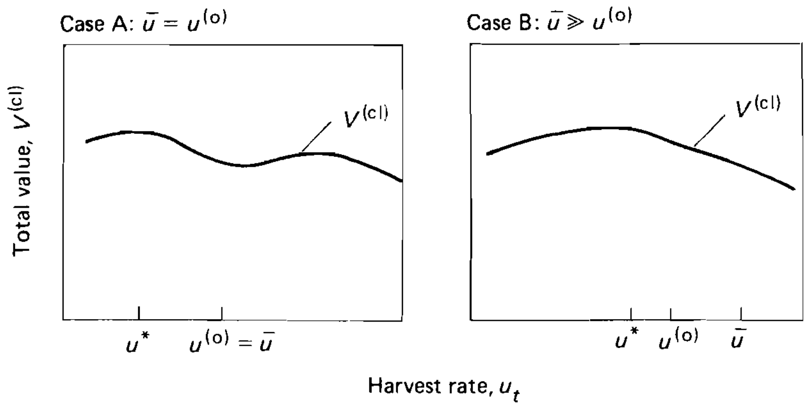

Figure 4.1. Examples of how the long-term value of harvests can be broken down into components as functions of harvest rate. The total value is $V^{(cl)}$. In case A, higher probing values away from the nominal $u^{(o)}$ imply that the optimum u^* is far below $u^{(o)}$. In case B, even using $u^{(o)}$ is informative since it is far from the historical average $\bar{u}$. (Part of *Figure 9.10* in *Adaptive Management of Renewable Resources.)*

There are at least two ways to avoid hard choices between passive and active adaptive policies. One is to make use of spatial structure within the managed system; most renewable resources are aggregates of smaller "replicate" substocks that are likely to be informative about one another (display similar responses to disturbance). Provided that the replicates do not each have a "dependent economic community" (harvesters, processors, resort owners, etc.) that cannot easily move its activities to other replicates, there can be considerable flexibility to experiment with harvest rate trade-offs between replicates (increase harvest in some, reduce in others by moving harvesting effort) without significantly changing the overall performance (yields, employment generated, etc.) of the managed system. Beyond offering opportunities for economic trade-offs between replicate substocks, spatially structured systems offer the possibility of scientific control (in the experimental sense) of the effects of large-scale environmental factors that may simultaneously affect several replicates, but be confounded within each replicate with the effects of local biological and policy changes.

A second way to avoid hard choices is to invest in better monitoring programs (so that smaller changes can be detected) and in socioeconomic programs that will confer greater flexibility to respond when experiments start to show unfavorable results. Often, high harvest rates and production enhancement programs are allowed to continue long after their deleterious effects have become obvious, simply because cutting back on them would cause immediate and politically unacceptable hardships for the harvesting industry. Socioeconomic programs that might prevent this pathological dependence include license limitation (to prevent the number of harvesters from becoming too large in the first place), subsidies for retraining and investment in other industries, and insurance schemes to tax the industry during good times so as to provide financial assistance during bad times.

The most risky "experiments" in renewable resource management have involved populations that are subject to increasing natural difficulties as stock sizes decline. For example, lake trout in the Laurentian Great Lakes of North America are preyed upon by a parasitic fish, the sea lamprey (*Figure 4.2*). When trout are abundant, the number killed by lamprey is small compared to the trout population size and there can be a stable "balance" or equilibrium. If trout harvest rates increase and their abundance declines, the number killed by lamprey does not decline proportionally (lamprey are efficient at finding trout even when the trout are scarce), so the lamprey kill becomes progressively more important and can cause the trout population to suddenly crash to a very low level. One management strategy in such situations is to keep harvest rates very low, so that the "cliff edge" for sudden collapse is not approached. However, trout yields are higher near the cliff edge and the edge moves in time (changing ecological parameters), so that it is difficult to find a consensus on just how low a harvest rate is safe enough. An adaptive strategy, called a "surfing policy", would be to let the harvest rates increase until a

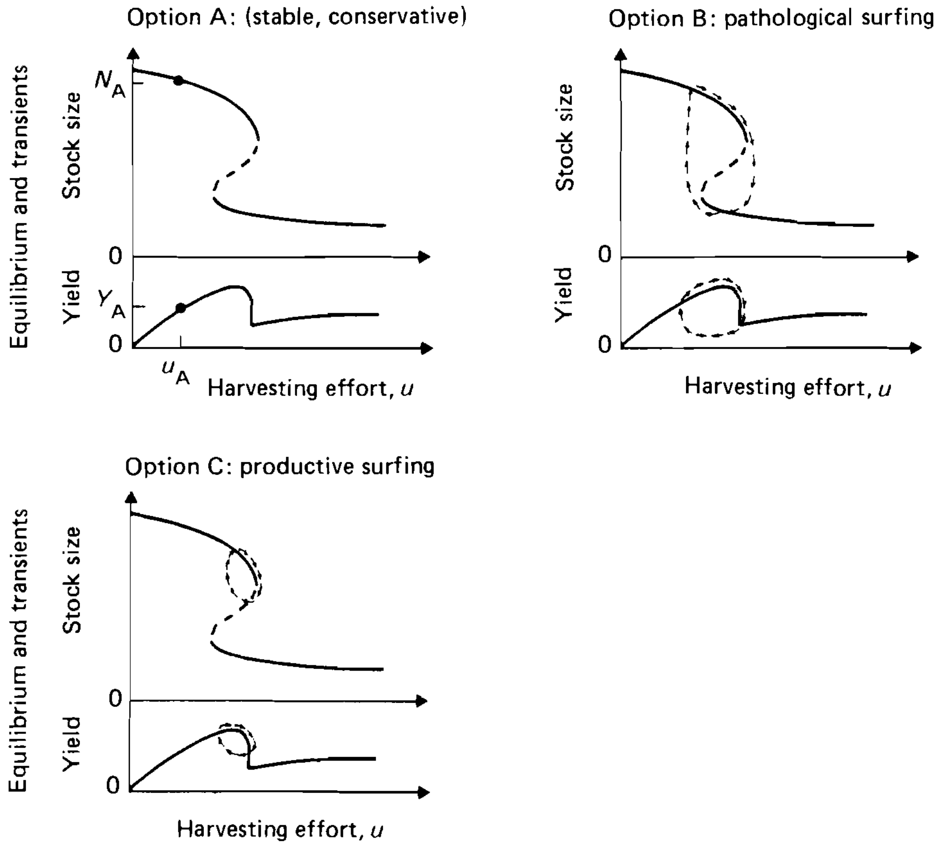

Figure 4.2 Three policy options for regulation of harvesting effort on lake trout in the Great Lakes. In option A, effort is kept low and steady. In option B, effort is allowed to increase until a major collapse occurs, and then there is a long recovery period. In option C, effort also increases until collapse starts, but detection and response to the collapse is much faster. B and C are "surfing" policies. (*Figure 11.1* in ***Adaptive Management of Renewable Resources.***)

collapse begins, then cut back quickly so as to allow recovery. The success of such a policy depends critically on two factors noted above:

(1) How early the collapse is detected (quality of the monitoring system).

(2) The flexibility of the management system to quickly cut back on harvests.

In the lake trout example, flexibility is the key limiting factor: collapses can be quickly detected with existing monitoring programs, but harvest rate reductions are highly political issues (a large tourism industry depends partly on the trout fishery) requiring perhaps years (and very clear evidence of collapse) to debate and implement. If greater flexibility could be achieved, trout yields under a surfing policy would be cyclic (collapse–recovery–collapse...), but would be higher on average than is now considered safe.

5

CONCLUSIONS

There is still much to learn about adaptive management, particularly in terms of how to design imaginative policies that make use of spatial replication and permit more flexible responses to natural and man-made surprises. The key problem now is not how to gather more data or construct more models in the hope of making more accurate predictions, but rather to develop a broader consensus about what the major uncertainties are and about the crucial role of ongoing management decisions in providing the experiments needed to resolve these uncertainties. When we begin to more widely embrace uncertainties and hard decision choices, rather than to pretend that future study will do the job, human ingenuity will be quick to find the imaginative options and wise compromises that are so badly needed.

6

CONTENTS OF ADAPTIVE MANAGEMENT OF RENEWABLE RESOURCES

7
THE AUTHOR

Carl Walters is a Professor at the Institute of Animal Resource Ecology, The University of British Columbia, Vancouver, Canada. Professor Walters was Deputy Leader of IIASA's Ecology Project in 1974–75 and in 1982–83 he was Leader of the Project on Adaptive Policy Design for the Sustainable Use of Resources. He has been heavily involved in the development of rapid techniques for teaching systems analysis and mathematical modeling to biologists and resource managers, employing problem-oriented workshops and seminars. He also undertakes basic research on problems of adaptive control, as applied to sequential decision making in renewable resources, and maintains a field research program in aquatic ecology.

8

PURCHASING ADAPTIVE MANAGEMENT OF RENEWABLE RESOURCES

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