Fisheries management science: the framework to link biological, economic, and social objectives in fisheries management

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Abstract

Fisheries management in the future will require that biological assessments be combined appropriately with operational, social, and economic considerations toward effective management of complex fisheries systems. This is not currently being done in fisheries management because of: (i) the lack of a conceptual and organizational framework for integrated and participatory decision making, and (ii) the lack of more appropriate methodologies for dealing with diverse sources of information, interdisciplinary objectives, and the inherent uncertainty of these systems. An integration of traditional "fisheries science" with other aspects of "fisheries management" and the field of "management science" in a new discipline of "Fisheries Management Science" is proposed. FMS is defined as "the rigorous application of the scientific method of problem solving in the development of strategic alternatives and their evaluation on the basis of objectives that integrate biological, economic, social, and operational factors into management decision making".

Management science or operational research provides guidance in methodologies for complex decision making and problem resolution. A multidisciplinary decision framework is proposed involving the following key steps: (1) specification of quantifiable objectives and constraints; (2) modelling of the expected multicriteria performance of a range of proposed management decisions; (3) risk assessment through descriptions of the expected variability in performance measures; (4) risk management through analytical evaluation of risk and ranking of alternate solutions; and (5) continuous monitoring and improvement of past decisions including deviations from expected performance and corresponding adjustment of future alternatives toward achieving strategic objectives.

Keywords: Fisheries management, conceptual and organizational framework, interdisciplinary, decision making, objectives, risk assessment, expected variability in performance measures.

La science de la gestion des pêches : le cadre général pour associer objectifs biologiques, économiques et sociaux dans la gestion des pêches.

Résumé

La gestion des pêches nécessitera dans le futur que les évaluations biologiques soient combinées, convenablement avec des considérations opérationnelles, sociales et économiques proches de la gestion effective de systèmes de pêche complexes. Cela n'a pas été couramment réalisé pour la gestion des pêches à cause de : (i) l'absence d'un cadre conceptuel et organisationnel pour prendre en compte des processus de décision intégrés et participatifs, et (ii) l'absence de méthodologies plus appropriées pour fusionner plusieurs sources d'information, des objectifs interdisciplinaires, et l'incertitude inhérente à ces systèmes. On propose ici une intégration de « la science des pêches » traditionnelle avec les autres aspects de la « gestion des pêches » et le champ des « sciences de la gestion » le tout dans une nouvelle discipline dite « Science de la Gestion des Pêches ». La Science de la Gestion des Pêches (SGP) est définie comme « l'application rigoureuse de méthodes scientifiques au problème résidant dans le développement de stratégies alternatives et leur évaluation sur la base d'objectifs qui intègrent des facteurs opérationnels, économiques, biologiques et sociaux dans les processus de prise de décision ».

La science de la gestion ou la recherche opérationnelle offrent des acquis méthodologiques face aux processus complexes de prise de décision et aux problèmes de résolution. Un cadre de décision multidisciplinaire est proposé prenant en compte les niveaux fondamentaux suivants : (1) la caractérisation des objectifs et contraintes quantifiables ; (2) la modélisation des performances multi-critères escomptées au niveau de décisions de gestion ; (3) l'évaluation du risque considéré au travers de la variabilité escomptée au niveau des mesures de performance ; (4) les risques de gestion considérés au travers des évaluations analytiques du risque et des solutions alternatives; et (5) le suivi en continu et l'évaluation des décisions antérieures incluant les écarts par rapport aux performances escomptées et correspondant aux ajustements des alternatives futures proche de l'aboutissement des objectives stratégiques.

Mots-clés : Gestion des pêches, interdisciplinarité, objectifs, évaluation du risque, variabilité attendue au niveau des indicateurs de performance.

INTRODUCTION

Among the fisheries science community, published literature (ICES 1993, Shotton, 1993; Smith *et al.*, 1993; Pearse and Walters, 1992; Serchuk and Grainger, 1992; Wooster, 1988; Larkin, 1988; Wilimovsky, 1985) has recognized the need for change in current approaches to fisheries management. However, the calls for significant change have not yet been heeded. It is significant that most suggestions for change still retain a strict organizational gap between biological evaluation of the stock of fish and aspects of fisheries operations (*e.g.* fish habitat maintenance, enforcement of regulations, socioeconomic performance), including the actual process of decision making (that is often unstructured and politically-charged).

Two significant meetings held in 1994 – the ICES Annual Science Conference (this volume) and the American Fisheries Society Annual Meeting – recognized the need for linking biological, economic, and social aspects of fisheries management.

The purpose of this paper is to present the view that the required change in fisheries management toward integrated strategic management be carried out through a structured systems framework for problem solving that must co-ordinate the efforts and objectives of all participants in the fisheries system. In this context, we define a new organization and discipline for fisheries management which we call "Fisheries Management Science".

This paper extends this concept and emphasizes the view that a more fully integrated systems analysis – together with the organizational change designed to reflect this approach – are required to advance fisheries management into the next century.

Consider a simplistic fisheries system comprised of the following participants:

(1) *The harvesters* – dedicated, full-time fishermen targeting a single species fish stock, motivated by lifestyle and increased earnings, with low opportunity costs (*i.e.* few other alternatives exist whereby they may earn a living).

(2) *Fisheries scientists* – charged with a "conservation" mandate that includes regular stock assessment responsibilities and the provision of biological-based advice to decision makers regarding seasonal exploitation limits.

(3) *Fisheries managers* – charged with the role of monitoring and enforcing fisheries regulations including the assigned seasonal harvesting limits.

(4) *Decision makers* – political leaders mandated by law, ultimately responsible for the conservation and sustainability of the fish stock, while maintaining a viable fishing sector through decisions that assign harvesting limits for each season.

As long as the conflicting goals of stock conservation and fish exploitation leading to sector viability are satisfied, the operation and equilibrium of the simplified fisheries system is not challenged by the participants. The resource, as far as fisheries scientists are concerned from their independent analyses, is "healthy", fishermen are earning "appropriate" wages, fisheries managers are independently monitoring and enforcing the terms of the existing regulations, and decision makers are satisfying their constituents with minimal complaints or lobbying for change.

Figure 1 illustrates the management process of the simple system. The process is characterized as a linear, reductionist decision making process whereby each of the participants contribute in an independent fashion to the final decision and its consequences.

Eventually, conflicts can be expected to arise in this system from exogenous factors that directly affect the stock status, the economic viability status, or both simultaneously. When equilibrium is disturbed and conflicts arise, tradeoffs must occur between the goals of stock "conservation" and economic viability. Moreover, all the participants in this system will converge on the decision makers to influence this tradeoff.

To complicate matters, we might realistically assume that the measure of stock status has the undesirable quality of being very difficult to determine given only partial observability (from catch or surveys) of the fish stock. In contrast, the economic status of the fishing sector is an immediate and directly observable measure. The acknowledged variability and uncertainty associated with measuring stock status over time translate into a tendency in the short-run for decision makers to discount biological advice if it is based on ill-defined or vague "conservation" measures, in favour of improved harvesting viability that would be anticipated immediately by higher exploitation on the stock. Alternatively, exploitation decisions that are felt by the harvesting sector to be overly protective of the stock will undoubtedly put stress on the regulations in place and the fisheries managers responsible for enforcing the regulations. Ultimately, more lobbying pressure will be applied to the decision makers to accommodate their conflicting objectives. Finally, once the conflict mechanism has been triggered, the pressure on the system will not likely dissipate even in the event the system returns to a more generally acceptable "equilibrium". Memories are long when lifestyles are at risk, and the potential costs of not participating in the political influence game far outweigh those of participating.

The simplistic model is an analogy for the structure of actual fisheries systems today. By way of example, the groundfisheries systems of the Canadian North Atlantic that are currently undergoing a difficult period of closures due to low stock levels coupled with socioeconomic stress have manifested the following observations (Smith *et al.*, 1995):

(1) Disillusionment among fisheries scientists with "political interference" relative to decisions taken that do not strictly adopt the "scientific advice" developed in good faith toward the primary goal of stock conservation and sustainability.

(2) Mistrust of harvesters by fisheries managers who expect violations of fisheries regulations to occur and are frustrated by their lack of ability and resources to deter "cheaters".

(3) Mistrust of regulators and scientists by harvesters who do not fully understand the basis for biological advice nor the cost of increasing and mounting restrictive regulations imposed on them.

(4) Discontentment with the management status quo due to resource restrictions and cutbacks, catastrophic fishery failures, and, especially in times of economic downturn, general public disapproval.

In this time of crisis in the fisheries in Atlantic Canada and elsewhere, an opportunity exists to adopt change in the way fisheries are managed. This change emphasizes management of the entire fisheries system as an integrated, structured decision making process, as opposed to the disciplinary, independent participants structure of the current system. The emphasis on "management" implies that all aspects of the fishery system be taken into consideration. Further aspects of the proposed system approach are described below.

SYSTEMS ANALYSIS AND THE SCIENTIFIC METHOD OF PROBLEM SOLVING

The recent and recurring difficulties in fisheries management are symptomatic of problems experienced in fisheries worldwide for the past several decades (Ludwig *et al.*, 1993; Rosenberg *et al.*, 1993). The current "reductionist" management paradigm described previously is not dealing effectively with the emerging problems and crises. What is required is a shift in the current paradigm that would lead to more successful approaches to dealing with the problems at hand.

A paradigm shift is caused by emerging problems (crises, paradoxes, anomalies) that are difficult or impossible to be dealt with within the current paradigm (Kuhn, 1970). New paradigms can gain their status because they are more successful than their competitors in solving current problems. Systems approaches to problem solving have been successful in industry and large scale ventures (*e.g.* missions to space) noted for their single purpose and integrated approaches.

In order to address the need for new methodologies to accommodate the fisheries management paradigm shift, we look to the field of systems analysis and its tools taken from operational research. Miser and Quade, 1985 state that,

"The aim of systems analysis is to use systems thinking and methodology (including methodological tools inherited from operations research) for analyzing complex problem situations that arise in private and public enterprises and organizations as a support for policy and decision making."

As the provider of tools for problem solving, operational research or management science is crucial to the development of systems thinking for the fisheries management problem. Operational research is carried out by the rigorous application of the "scientific method of problem solving". This is a process that begins by

"carefully observing and formulating the problem and then constructing a scientific (typically mathematical) model that attempts to abstract the real essence of the problem. It is then hypothesized that this model is a sufficiently precise representation of the essential features of the situation, so that the conclusions (solutions) obtained from the model are also valid for the real problem. This hypothesis is then modified and verified by suitable experimentation. Thus, in a certain sense operations research involves creative scientific research into the fundamental properties of operations. However, there is more to it than this. Specifically, operations research also is concerned with the practical management of the organization. Therefore, to be successful it must also provide positive, understandable conclusions to the decision maker(s) when they are needed." (Hillier and Lieberman, 1974, p. 3).

Existing methods in the field of operational research/management science represent a scientific, analytical foundation for the required paradigm shift in fisheries management. Moreover, management science approaches have been used successfully for many years in dealing with segmented problems in fisheries systems (*see* Lane, 1992 and Lane, 1989*a* for examples of operational research in fisheries management.)

The role of management science in fisheries is as the problem solving catalyst in the linkage of the biological-based and analytical methodologies of fisheries science with the operational, fisheries-related activities of fisheries management. The resultant interconnection among the tripartite of Fisheries Science – Fisheries Management – Management Science defines the discipline of "Fisheries Management Science". FMS is defined as the rigorous application of the scientific method of problem solving in the development of strategic alternatives and their evaluation on the basis of objectives that integrate biological, economic, social, and operational factors into management decision making (Stephenson and Lane, in press).

The application of the scientific method of problem solving to the general fisheries management system requires analysis of the following key components discussed in more detail below.

1. System and problem definition – identification of the problem, objectives, decision alternatives, controllable and uncontrollable variables, and constraining factors.

2. Model construction – development of mathematical models that describe the system dynamics and the problem elements including quantitative measures of evaluation for alternative solutions and collection, analysis, and evaluation of all relevant problem data.

3. Monitoring and control – comparison of the actual evolution of the system with predicted system status, including feedback measures to be initiated when significant differences occur.

THE FISHERIES SYSTEM

System definition

The universe of the fisheries management problem includes many factors: the ecosystem and physical environment in which the exploited stock exists, including predators, prey, variability of change, etc.; the age-structured fish population, growth and recruitment dynamics, stock migration dynamics; fishery sector, industrial structure, harvesting and processing dynamics and capacity, social implications, demographics of harvesting and processing labour, revenues and costs of operations; and fisheries regulations in effect, area, capital restrictions, and reactions of harvesters to regulations. This is a very complex system. Consequently, attempts to manage such a system within some specified bounds will be difficult. Nevertheless, the problem of management can be specified and must be resolved on a regular basis if management is to be achieved.

Controllable elements of the fishery system include those variables that may be manipulated as direct or indirect controls on the system, *e.g.* annual aggregate TACs, and vessel quota allocations, the capacity and kind of fishing effort/intensity, temporal and spatial distributions of harvesting (*e.g.* area closures, gear restrictions), and measures to improve or restore ecosystem health and habitat enhancement. System elements that are uncontrollable include: exogenous environmental effects, predator-prey interrelationships, annual stock-recruitment behaviour, natural mortality, intraseasonal stock distribution (migration), stock interannual growth, catastrophic events, political expediencies and agenda, and exogenous markets impacts.

Problem definition

In general terms, the problem facing decision makers is how to use the controllable elements of the fisheries system in order to achieve specified objectives within the confines of system constraints.

Decisions

The complexity of the system guarantees that there will be many alternative options for developing fisheries management decisions through manipulation of parameters for the controllable elements. From these alternatives, feasible decisions can be distinguished from infeasible decisions relative to the constraint restrictions of the problem.

Constraints

Current conditions and prespecified restrictions (*e.g.* on the level of seasonal exploitation) contribute to defining system constraints. In particular, biological considerations that quantify and define "conservation" and take into explicit account limits on the rate of stock growth represent constraining factors in the fisheries system problem. As Wooster (1988) states,

"To understand the process, we first examined the objectives of management, especially the biological objectives, which we thought could be defined unequivocally, whereas social welfare objectives, being heavily loaded with values, would be more controversial. But it soon became apparent that biology imposed *constraints* rather than inspiring *objectives*. Fisheries were managed to obtain social, not biological, benefits, although the magnitude of the benefits, both now and in the future, was constrained by the continuing productivity of the resource."

Biological constraints may take the form of annual schedules of desirable stock target levels whose measurements are directly related to stock abundance estimates, *e.g.* from surveys. Long term strategic targets also require specification of intermediate and short term milestones. More importantly, the specification of stock target constraints also provides feedback on controllability and decision accountability. Decisions that do not achieve prespecified targets will require an adjustment be made in the direction and our understanding of the ability to manage the stock. Conversely, decisions which achieve the milestones and strategic targets would be evaluated as successful.

Objectives

The fisheries management problem definition requires a concise statement of problem objectives in order to evaluate the developed alternatives. More specifically, quantitative measures of decision alternatives must take into account valuation issues of the fishing activity. As Larkin (1988) states,

"The approach must be anthropocentric. It is a contradiction in terms to speak of biological objectives of fisheries management. Much more logical is to speak of biological constraints to management... The real questions are: what should be the biological constraints and what should be the social objectives. The answers are: whatever is necessary to preserve future biological options until we know more biology and, whatever seems appropriate to the society at the time." (p. 289)

Consistent with the scientific method, fisheries objectives must be stated as value-laden and measurable in terms of benefits derived from the social and economic activities of the fishery sector.

SYSTEM MODELLING

The level of complexity of the fisheries system requires a particular approach to modelling the various elements of the problem discussed above.

The "holistic" or all encompassing approach to systems modelling requires a large degree of empirical information to understand all interrelated aspects of the system "at once". For complex systems, these requirements together with inherent system variability conspire to reduce interpretability and often add merely to intuitive and qualitative system sensitivities. "Ecosystem modelling" approaches suffer from these deficiencies and, although tried in the past, have generally been unsuccessful in providing practical information for fisheries management decision making purposes.

System approaches that breakdown components into approximately independent, sequential steps, have an "assembly line" approach to system modelling and problem solving. This "reductionist" approach (*fig.* 1) leads to problems stemming from the potential imbalance among components (*e.g.* the historical dominance of biology in fisheries), limited connectivity (*e.g.* fisheries scientists do not deal directly with fisheries managers) and incidental feedback among system participants (*e.g.* anecdotal information from harvesters related to stock abundance

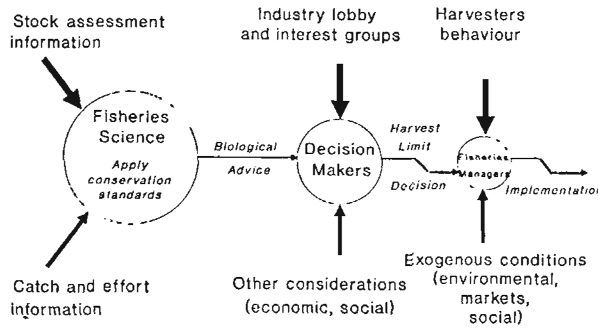

Figure 1. – Fisheries decision making system.

status), and a lack of overall focus applied to the original, ill-defined management problem.

An alternative methodology decomposes the complex system problem into definable components for individual analysis while defining links and interconnectivity between components for later aggregation in a unified system response. As Klir, 1991 states,

"Holism, in opposition to reductionism, was undoubtedly one of the main roots from which systems movement sprang. Initially, a tendency toward full commitment to holism and a total rejection of reductionism was quite visible in systems movement. Over the years, this extreme position became slowly moderated. Now, the two doctrines are viewed, by and large, as complementary. While holism is accepted as a thesis that is correct on logical grounds... and consequently, desirable to follow as an ideal guiding principle, it is recognized that its applicability is often limited on pragmatic grounds... By studying the relationship between wholes and parts from the methodological point of view, current systems thinking goes far beyond thinking molded from either reductionism or holism. We may say that it represents a synthesis of the reductionist thesis and the holistic antithesis." (p. 30-31.)

In order for this complementary holistic and reductionist approach to be effective, a high degree of responsibility is required within each component to maintain balance and focus on the defined overall problem. An integrated and interdependent decision analysis framework with feedback is illustrated in *figure* 2. The circular process embodies the feedback loop of successive decisions based on the integrated advice developed from all relevant components of the fishery system and implemented into fisheries operations.

The system modelling process incorporates the decomposition and aggregation methodology for the analysis of the system. Specific modelling components enhance information for decision making at each stage of the modelling process. Models at each stage are characterized by value-based, measurable objective functions, biological constraints defining "conservation" in terms of stock status, and decision

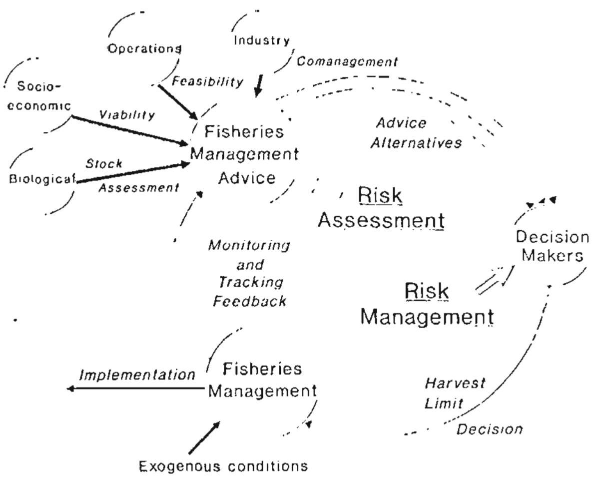

Figure 2. – Fisheries system analysis framework.

alternatives defined in terms of actual operational control parameters.

For example, the modelling process begins by describing the system through a general stochastic model that incorporates (1) underlying system dynamics, and (2) measures of data observation reliability and errors associated with stock assessment and abundance indices. The results of this analysis characterizes high-valued and feasible (*i.e.* constraints satisfying) control strategies that merit further examination (Lane, 1989*b*).

Next, candidate control strategies' biological (stock) and economic (fishery) performance are explored in more detail through a deterministic bioeconomic model analysis. Then, simulation modelling is used to reflect system variability including errors for observations, and natural sources of variation. The results of the simulation provide probability distributions of the performance measures which assess the riskiness of the alternative decisions relative to the biological and other targets (Lane and Kaufmann, 1993). Finally, risk management techniques are applied through multiattribute utility analysis to rank alternative decision options (Stephenson and Lane, 1993).

The technology for the precise bioeconomic model development and analysis of the kind suggested here has been available for several decades in the operational research literature and fisheries literature (*e.g.* Clark, 1976; Bodily, 1992; Smith *et al.*, 1993), and is more readily adoptable today through advances in computing power.

MONITORING AND CONTROL

Current fisheries management regimes make decisions as part of a seasonally repeated, and essentially independent annual review process. Consistent with the notion of accountability of decision making and strategic planning, the problem solving process considers the interrelated decisions made over time as part of a long-term strategic process moving toward well-defined, multiattribute management goals. This viewpoint requires adoption of "total quality management" – ongoing monitoring and tracking of decision performance *vis-à-vis* the objectives (Drucker, 1954), and continuous revision, feedback and improvement over time (Deming, 1982).

The purpose of monitoring and control is to validate and verify the expected performance of alternative management decisions. Model control is anticipated through the expectation of future observations. For a given strategy, the dynamic model can be used to predict the expected results of the next period, *e.g.* annual stocks survey results, average weight at age, etc. When expected results vary significantly from actual observations, this "signal" should cause a predefined adjustment in decision strategy to take effect. The capacity of the system to be controlled is measured in terms of the extent to which adjustments are made in successive decision periods. Moreover, system control is implied by the ability to anticipate the general status of the system over time. Systems which are "out of control" do not behave as expected over time, and would require adjustment in decision making and model reliability in order to be brought "under control". Decision strategies that result in expected signals over time are held accountable accordingly. Moreover, the opportunity to test the system adaptability and to carry out scientific experimentation is facilitated.

The need for accountability in fisheries decision making is imperative. The consequences of not being measurably accountable may have serious implications for the system participants and the resource.

CONCLUSION

This paper elaborates on principles of "fisheries management science" using systems analysis approaches for decision making in fisheries management. Key components of fisheries management problem solving include (1) defining clearly all aspects of the management problem including quantifying value-based objective measures; (2) specifying explicit stock targets and socioeconomic objectives over time and establishing an appraisal system for monitoring and tracking decision making performance; (3) establishing a modelling process for developing and evaluating alternative strategic decision options under conditions of uncertainty.

To be effective, application of the systems approach would require restructuring existing institutional arrangements so that fisheries scientists, fisheries managers, and harvesters have the opportunity to provide relevant information through an integrated, participative team approach to problem solving.

The integration of biological, economic, and social aspects of fisheries management as proposed in this paper is hampered by differences in language, methodology of the three disciplines. Progress in this linkage requires study of specific cases and situations. This is best done by interdisciplinary teams actively cooperating in developing and presenting the management illustrations.

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