NATURAL RESOURCE MODELING
Volume 15, Number 3, Fall 2002

ECONOMIC MODELS OF MARINE PROTECTED AREAS: AN INTRODUCTION

USSIF RASHID SUMAILA
Fisheries Centre
University of British Columbia
2204 Main Mall
V6T 1Z4, Vancouver B.C., Canada
E-mail: r.sumaila@fisheries.ubc.ca

ANTHONY T. CHARLES
Management Science/Environmental Studies
Saint Mary's University
Halifax N.S. Canada B3H 3C3
E-mail: T.Charles@StMarys.ca

This paper aims to achieve two goals. First, it provides an overview of marine protected areas (MPAs)—a concept that is attracting widespread attention worldwide—and the role of economic analysis and modeling in designing, implementing and evaluating such marine protected areas. Several major considerations to be taken into account in economic modeling of MPAs are also discussed. Second, the paper serves as an introduction to a pair of special issues of the journal, *Natural Resource Modeling*, Vol. 15, Nos. 3 and 4, 2002, containing a selection of papers presented at the International Conference on the Economics of Marine Protected Areas held July 6–7, 2000, in Vancouver, Canada. The conference provided a first opportunity for academic, government and private sector actors to share ideas, information and models relating to the economic analysis of Marine Protected Areas, as tools in fishery management and marine ecosystem conservation. These special issues follow along similar lines, providing, apparently for the first time within an international journal setting, a comprehensive focus on the economics of MPAs.

The paper begins with the introduction of the concept of marine protected areas and the discussion of relevant economic modeling considerations, before turning to an overview of the ten papers included in the special issues. It should be noted that this paper is not meant to be a comprehensive review of the literature, and therefore only a sampling of publications relating to MPAs is provided here. The papers within the special issues together provide a much fuller bibliography on the subject.

Marine Protected Areas. The goal of a *protected area*, as its name suggests, is to protect a specified location from certain human impacts. For example, a national park is a protected area typically meant to maintain a 'natural' environment to some degree for ecological, economic, cultural, recreational or other reasons. Precisely what such an area is being protected from can vary greatly, but it is most often some form of ongoing exploitation (such as harvesting or extracting natural resources) or some form of new economic development (such as construction of housing or tourist facilities).

Marine Protected Areas are simply protected areas in the ocean—designated ocean spaces within which human activities are regulated more stringently than elsewhere, typically to achieve certain conservation objectives. Indeed, a primary focus of MPAs is on the conservation of marine living organisms and their habitats, as well as ecological systems and functions, through the regulation of "extractive" or potentially polluting commercial uses such as fishery harvests, waste disposal and mineral development, among others (Hoagland et al. [2001]). The regulation of human uses can range in format from marine reserves ('no-take' areas in which any form of extraction is prohibited) to 'zoned' areas in which a variety of uses are permitted to some extent and managed in an integrated manner. Specific regulations might prohibit some uses (such as seabed mining), place limits on some (e.g., fishing) and control the technologies used for others (e.g., shipping).

MPAs are of great interest both as a fishery management tool and as a tool for 'integrated ocean management' (Charles [2001]). On the one hand, an MPA can be used for specific fishery management ends such as restricting the fishing fleet's impact on a fish stock, or protecting an ocean area where a certain fish population spawns or where juvenile fish congregate. On the other hand, MPAs often involve much more than fisheries. As but one example, the Soufrière Marine Management Area in St. Lucia (Caribbean) is a form of MPA that is subdivided into zones to provide protection to certain coral reef areas, opportunities for fishing in other areas, locations for yacht mooring and recreational activities, and 'general purpose' areas (Soufrière Regional Development Foundation [1994]). Thus, there may be a dual nature to MPAs, in which there is often a focus on fisheries matters, but also a broader role in multi-use marine management. This creates a richer set of issues to address in analyzing MPAs than is the case with most management measures that focus solely on the fishery, such as total allowable catches (TACs), catch quotas, effort controls, gear limitations and the like.

Research to date on MPAs has tended to focus in two directions. First, an abundant literature has developed describing the potential (and in some cases, demonstrated) ecological *benefits* of MPAs—notably in terms of ecosystem health, biodiversity and greater long-term fish harvests (e.g., Roberts et al. [2001]). The focus in this literature on ecological factors reflects the fact that MPAs have largely attracted the attention of natural scientists to date, while the emphasis on the benefits of MPAs reflects a sense that the implementation of MPAs is generally a positive move from an ecological perspective.

The other major direction in the literature deals with the *process* by which an MPA is developed and implemented, and the policy issues involved (see, e.g., Shackell and Willison [1995], National Research Council [2001]). This literature on *process* is substantial largely because it deals with the need for conflict resolution in MPA design, which reflects the reality that in practice, there is often opposition to the implementation of MPAs.

The existence of these two trends in the MPA literature, one highlighting the potential *benefits* of MPAs, and the other the need to deal with *opposition* to MPAs, raises a natural question: If MPAs produced only benefits, why would there be opposition to their introduction? The answer, of course, is that the implementation of MPAs, like human actions of any sort, produces both benefits *and* costs. Furthermore, these benefits and costs do not appear uniformly: some stakeholders may benefit more than others, while some may incur higher costs than others. What is more, both benefits and costs may appear at different stages over time.

The importance of addressing such matters is now clearly recognized. Indeed, while successful development and implementation of MPAs certainly involves technical and knowledge-based matters (e.g., optimizing MPA design from an ecological perspective), perhaps the dominant challenge lies on the human side, in dealing with the various connections between MPAs, ocean users and coastal communities, and in optimizing the overall benefits obtained by society (Farrow [1996]).

Approaches to the Economic Modeling of MPAs. From the above discussion it is clear that economics and other social sciences have a major role to play in the design, implementation and evaluation of MPAs. Appropriate methodologies are needed to address the balance among benefits and costs, to balance the multiple goals involved in multi-use management and to understand and analyze the human dynamics of decision making. While the need is clear, there is as yet a dearth of literature incorporating such approaches into MPA analyses. Therein lies the motivation for these special issues and for the conference from which they emerged.

In particular, the sort of economic analyses required includes not only the traditional optimization and behavioral methods found in, for example, bioeconomic natural resource models, but also aspects of multi-objective analysis, contingent valuation and socioeconomic studies that seek to inform on human aspects ranging from conflict resolution to participatory decision making.

The challenge of addressing the economics of MPAs may be viewed on a number of fronts:

• *Disciplinary Emphasis.* MPA analyses are carried out across a range of 'disciplinary emphases.' Since MPAs were originally conceived as mechanisms for ecosystem protection, there is bound to be a biological and biophysical element involved in their analysis. At the same time, MPAs really have as much to do with people as nature. Thus there is a need to incorporate social and economic aspects. Analyses range from those lying primarily on the ecological side but with some social and economic aspects incorporated, to those focused on human—social and economic—aspects, but usually with the incorporation of some components of the natural sciences (such as the incorporation of population dynamics in the models).

• *Theoretical vs. Applied.* Theoretically-oriented analyses focus broadly on obtaining insights into the dynamics and performance of MPAs, and can be subdivided into two principal approaches: (a) classical bioeconomic models—sometimes static but most often dynamic in nature, incorporating fish population dynamics, a net benefits function, and a present value calculation with discounting (e.g., Conrad [1999]), and (b) simulation studies—which, when oriented toward generating theoretical insights, typically involve use of representative parameter values and suitable sensitivity analysis (e.g., Holland and Brazee [1996], Polacheck [1990]). On the other hand, applied research is oriented toward analyzing specific case studies and serves both to provide an understanding of particular MPA situations and to help build a body of case studies that eventually can facilitate a meta-analysis of MPAs (Rowley [1994]).

• *Optimization vs. Behavioral.* Most MPA analyses can be classified as optimization-oriented or behavioral. In the former, emphasis is put on determining the 'best' MPA design by addressing such factors as the optimal size of the MPA and its shape and structure (especially the issue of whether a single large MPA is or is not preferred over a network of smaller MPAs: Ballantine [1994]). Temporal aspects are important in this regard, notably with respect to discounting over time, and intertemporal flows of benefits and costs. On the other hand, behavioral modeling focuses attention on understanding feedbacks between MPAs and ecological dynamics (how the various marine species respond to the presence and functioning of the MPA) as well as human dynamics (how people interact with the MPA, for example through changes in fishing and other use patterns, and even 'rent seeking' actions to increase individual net benefits from the MPA).

• *Stochastic Analysis.* MPA analyses vary in the extent to which they involve uncertainty. Models incorporating uncertainty (and thus requiring a stochastic analysis) recognize that one of the principal arguments made for MPAs is their use as an 'insurance policy'; specifically, from a fishery perspective even if other management measures fail, the MPA will ensure a certain minimal level of ecosystem and fish stock health (Clark [1996]). If the world were certain, such insurance would not be needed; thus, a stochastic analysis explores the economics of MPAs as insurance policies and the impact of an MPA within an environment that is randomly fluctuating and/or prone to structural uncertainty (Charles [2001]). Uncertainty clearly can arise in any part of a fishery system—the ecosystem, the economic system, social components or institutional aspects (Sumaila [1998]).

• *Spatial Analysis.* Since MPAs are inherently dealing with areas of ocean space, necessarily they involve spatial considerations. However, many studies of MPA economics, particularly those with a primarily theoretical focus, are based on aggregated spatially-homogeneous models. These serve a purpose, but spatially-heterogeneous models are needed to address such issues as the economically optimal placement of an MPA within a certain region, the desired 'design' of the MPA (in terms of shape and configuration), and how much of a fishery should be placed within an MPA to optimize net economic benefits.

• *Benefit-Cost and Distributional Issues.*

- What are the benefits? What are the costs?
- Over what time frame are benefits and costs measured? What is the intergenerational flow of these benefits and costs? How do we deal with discounting of future benefits and costs?
- What about equity issues? Who receives the benefits? Who incurs the costs? Do the benefits of MPAs reach those who suffer the costs? What about the differing levels at which benefits and costs occur: individuals and corporations (e.g., resource users), communities, regions?
- In measuring benefits, we must take into account all types of benefits (and costs), including consumptive uses (fishing, mineral extraction, etc.), non-consumptive uses (e.g., observation of wildlife, notably through tourism), non-use/existence value (the inherent value placed on the very existence of the protected area) and option value (the value placed on maintaining the marine ecosystem for possible future economic uses).
- In measuring benefits, we must take into account the direct net benefits accruing from all relevant economic activity, e.g., fisheries, tourism, extraction of non-renewables, the non-use benefits, existence value and option value; all of these must be measured at the appropriate scale—from the individual to the social and community levels, including the spin-off benefits that may arise

in the regional economy (e.g., increased post-harvest activity as a result of a more productive fishery).

Naturally, to properly address these questions requires suitable analytical methods, and in particular the use of resource modeling approaches. Therein lies the focus of this pair of special issues: a combination of modeling and economic analysis applied to MPAs. Furthermore, while the economic aspects of MPAs are deserving of attention, it must be recognized that one cannot restrict attention solely to that area—the study of MPAs involves both natural and social science components. Thus, to examine economic aspects, it is important to have a sound grounding in the ecological and physical realities of the marine system, as well as an understanding of the sociological and cultural realities that affect the acceptance of MPAs and the process for their implementation. The diversity of papers in these special issues attempts to meet this challenge.

Ten Contributions on the Economic Modeling of MPAs. Papers in the special issues of *Natural Resource Modeling* are predominantly model-based and together cover a broad range of economic aspects including bioeconomics, socioeconomics and various forms of microeconomics. (Note that a set of papers from the conference that addresses the economics of MPAs but with a less formal modeling basis may be found in *Coastal Management*, Vol. 30, No. 2, 2002.) The ten papers in these special issues are arranged largely according to their modeling methodology. In particular the majority of papers in the first issue take a theoretical focus, dealing with MPAs in the context of bioeconomic optimization, while the entirety of the second issue involves papers based on computational and simulation models, with the emphasis ranging from the economic to the more ecological.

The first issue starts with three theoretically-oriented papers exploring the desirability of MPAs and the factors affecting this desirability, using bioeconomic models.

The Economics of Marine Reserves by Hannesson builds on the author's previous work in examining the circumstances making MPAs desirable or undesirable economically. This paper analyzes the effects of marine reserves with open access in the fished area of the habitat, applying a logistic model for a population with a patchy distribution. The paper also examines a stochastic variant of the model. The analysis in this paper shows that when an MPA is introduced, the total fish population increases while the total catch declines for the most part. The stochastic variant of the model is used to show that the variability of catches may decrease as a result of protecting one of the sub-populations.

The Impacts of Marine Reserves on Limited-Entry Fisheries by Sanchirico and Wilen applies a spatial bioeconomic model to examine how various marine reserve options affect fishermen participating in limited entry fisheries. The authors show that win-win situations—where aggregate biomass and the common license (lease) price increase—can arise in biological systems where dispersal processes are prevalent, and the fishery prior to reserve creation is operating at effort levels close to those found under open access situations. They also illustrate that closing the highly biologically productive areas is not necessarily the best strategy, if the goal is to simultaneously improve both the economic and biological conditions in the fishery.

A Bioeconomic Analysis of Marine Reserves by Anderson uses a model with a Schaefer growth function and homogeneous productivity throughout the fishing area to conclude that, compared to a TAC policy, MPAs will achieve a given safe minimum biomass level and that the analogous marine reserve policy will achieve a lower equilibrium harvest level but will not result in an overcapitalized fleet or a shortened fishing season as with a TAC policy.

These theoretical papers are followed by one with a very different methodological approach. *Contingent Valuation of Marine Protected Areas: Southern California Rocky Intertidal Ecosystems* by Hall, Hall and Murray uses contingent valuation to determine the value placed by shore visitors on MPAs within a particular case study context. The paper develops and applies a method to estimate the benefit of more effective enforcement and management of MPAs designed to avoid coastal ecosystem decay, in particular estimating the Willingness to Pay (WTP) for enacting policies to reduce illegal collecting and on-site habitat disturbance.

The final paper in the first issue is Holland's *Integrating Marine Protected Areas into Models for Fishery Assessment and Management.*

This paper provides an important review of the role of modeling in fishery analysis with a particular focus on spatially-explicit models, and addresses one of the fundamental challenges for MPA analysts and resource modelers, that of incorporating MPAs into fishery models.

As noted above, the second issue in this set is devoted entirely to computational and simulation modeling, but contains a great variety of approaches among the five papers therein.

The first of these papers is *Fish, Fishers, Seals and Tourists*: *Economic Consequences of Creating a Marine Reserve in a Multi-Species, Multi-Activity Context* by Boncoeur, Alban, Guyader and Thébaud. This paper studies the economic effects of implementing a marine reserve in a habitat inhabited by two species in a predator-prey situation. The investigation was carried out with the aid of a bioeconomic model which is simulated using the software package known as STELLA. The paper finds, among other things, that creating a marine reserve has more complex economic implications than predicted in studies focused exclusively on one stock, or solely on commercial fisheries. More specifically, the model shows that the dynamics of the two interacting stocks reduces the benefits of the no-take zone for the fishing industry, while creation of this zone provides an opportunity for the development of ecotourism.

A Model for the Bioeconomic Evaluation of Marine Protected Area Size and Placement in the North Sea by Beattie, Sumaila, Christensen and Pauly develops a variant of the Ecopath with Ecosim ecosystem modeling framework to evaluate the use of MPAs in the North Sea in both ecological and economic terms. Optimal placement and size of MPAs are determined for four different policy options: (i) maximize economic rent only, (ii) maximize the existence value only, (iii) maximize the sum of economic rent and existence value, and (iv) maximize the sum of economic rent and existence value with the added constraint that trawlers are excluded from fishing. The paper finds that policy goals that do not include ecological considerations can negatively impact the rents obtained by the different fishing sectors. Under policy options that included ecological considerations, maximum benefits were derived from an MPA that covered 25–40% of the North Sea, placed along the southern and eastern coasts.

Marine Protected Area Performance in a Model of the Fishery by Sumaila uses a computational bioeconomic model to examine how MPAs affect the payoffs to the various players in the fishery under conditions of joint (cooperative) and separate (competitive) management. Results from this study indicate that MPAs can protect the discounted economic rent from the fishery if the habitat is likely to face a shock. It also shows that the economically optimal size of an MPA varies, depending on the exchange rate between the protected and unprotected areas of the habitat; whether fishers behave cooperatively or non-cooperatively; and the severity of the shock that the ecosystem may face.

The fourth and fifth papers in the second issue focus more on ecological considerations, albeit with an economic component. *A Model of Tropical Marine Reserve-Fishery Linkages* by Rodwell, Barbier, Roberts and McClanahan examines interactions between MPAs and fisheries in the context of a particular case study. The paper develops a deterministic model in discrete time which describes the interaction between the fish stock in the fished and unfished areas of the marine habitat. One key result of the paper is that total fishery catch will be greater with a reserve for almost all scenarios of fish and larval movement, if the fishery is already moderately to heavily exploited. Catches can be optimized without a reserve if the fishery is already facing low exploitation rates.

Fishery Benefits of Fully Protected Marine Reserves: *Why Habitat and Behavior Are Important* by Roberts and Sargant completes the set of papers in these special issues with an exploration of some determinants of optimal MPA design. The authors developed a discrete, size-specific model of a hypothetical fish population which was implemented using the software package STELLA. The paper demonstrates that establishing fully protected reserves in areas where migratory species, especially large pelagics like billfish, tunas and sharks are most under pressure from fisheries, could help maintain their long-term survival.

Conclusions. This brief paper has sought to highlight the major economic factors relevant to MPA creation and to lay out key aspects of the current state of knowledge concerning MPA economics, with emphasis on the most recent work reflected in these special issues. In particular, the first part of the paper has laid out a number of challenges that need to be resolved by economists working with other social scientists and ecologists, studying the efficacy of MPAs both as fisheries management and marine conservation tools. The second part of the paper has provided a summary and gateway to the ten papers included in the two special issues of *Natural Resource Modeling*. We are confident that the work reflected in these special issues will contribute significantly to advancing the research agenda on MPAs into the future.

Acknowledgments. The authors are grateful to all those who provided insights into MPA economics through their attendance at the International Conference on the Economics of Marine Protected Areas (July 6–7, 2000, Vancouver, Canada) and their contributions to the special issues of *Natural Resource Modeling*. Sumaila acknowledges the Norwegian Research Council and the Sea Around Us project of the UBC Fisheries Centre and the Pew Charitable Trusts, for their role as the principal funders of the conference from which this special issue emerged. Charles acknowledges support from a Pew Fellowship in Marine Conservation (Pew Charitable Trusts) and a research grant (#6745) from the Natural Sciences and Engineering Research Council of Canada. We must also thank the anonymous referees whose contributions have helped to significantly improve the quality of the special issues.

REFERENCES

W.J. Ballantine [1994], *The Practicality and Benefits of a Marine Reserve Network*, in *Limiting Access to Marine Fisheries: Keeping the Focus on Conservation* (K.L. Gimbel, ed.), Center for Marine Conservation and World Wildlife Fund, Washington, D.C., 205–223.

C.W. Clark [1996], *Marine Reserves and the Precautionary Management of Fisheries*, Ecolog. Appl. **6**, 369–370.

A.T. Charles [2001], *Sustainable Fishery Systems*, Blackwell Science, Oxford, UK.

J.M. Conrad [1999], *The Bioeconomics of Marine Sanctuaries*, J. Bioecon. **1**, 205–217.

S. Farrow [1996], *Marine Protected Areas: Emerging Economics*, Marine Policy **20**, 439–446.

P. Hoagland, U.R. Sumaila and S. Farrow [2001], *Marine Protected Areas*, in *Encyclopedia of Ocean Sciences* (J.H. Steele, S.A. Thorpe and K.K. Turekian, eds.), Academic Press, London, 1654–1659.

D.S. Holland and R.J. Brazee [1996], *Marine Reserves for Fisheries Management*, Marine Resource Econ. **11**, 157–171.

National Research Council [2001], *Marine Protected Areas*: *Tools for Sustaining Ocean Ecosystems*, National Academy Press, Washington, D.C.

T. Polacheck [1990], *Year Round Closed Areas as a Management Tool*, Natural Res. Modeling **4**, 327–354.

C.M. Roberts, J.A. Bohnsack, F. Gell, J.P. Hawkins and R. Goodridge [2001], *Effects of Marine Reserves on Adjacent Fisheries*, Science **294**, 1920–1923.

R.J. Rowley [1994], *Case Studies and Reviews*: *Marine Reserves in Fisheries Management*, Aquat. Conserv.: Marine Freshwater Ecosystems **4**, 233–254.

N.L. Shackell and J.H.M. Willison [1995], *Marine Protected Areas and Sustainable Fisheries*, Science and Management of Protected Areas Association, Wolfville, Canada.

Soufrière Regional Development Foundation [1994], *Soufrière Marine Management Area*: *Agreement on the Use and Management of Marine and Coastal Resources in the Soufrière Region, St. Lucia*, Soufrière Regional Development Foundation, Soufrière, St. Lucia.

U.R. Sumaila [1998], *Protected Marine Reserves as Fisheries Management Tools*: *A Bioeconomic Analysis*, Fisheries Res. **37**, 287–296.