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An Introduction to Spatial Modeling in Fisheries Economics

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Introduction

The catalyst for the articles in this special issue was a workshop on "Spatial Modeling in Fisheries Economics" sponsored by the United States National Oceanographic and Atmospheric Administration Fisheries Office (NOAA Fisheries) in October of 2002. The workshop evolved from discussions amongst fishery managers and scientists on the need to think more critically about the objectives and effects of spatial management of marine fisheries. These discussions are in response to the provisions in the Magnuson-Stevens Fishery Management and Conservation Act on the identification and protection of essential fish habitat (EFH) and Executive Order 13158, which calls for the development of a network of marine protected areas (MPAs) in the United States. The focus of the workshop was on the role that economists can play in designing and evaluating the cost effectiveness and efficiency of such policies and the methodologies needed for this task.

In many ways, the executive order on MPAs is symbolic of changes underway in ocean governance. First, in response to a growing body of evidence, management has begun to move away from a paradigm where fishermen and fish stocks are treated as if they are uniformly distributed across a featureless socioeconomic and ecological seascape to one that recognizes and responds to policy relevant spatial

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heterogeneity across all dimensions of fishery management. Second, the order highlights the importance of conserving natural and cultural heritage areas and the use of protected areas to ensure the ecological and economic sustainable use of the marine environment. Based on the recent increase in MPA proposals, it seems likely that in the coming years we will witness a movement to set aside areas of the ocean for conservation purposes that will rival the United States land conservation movement of the early 20th century.[1]

These changes in ocean governance pose both a challenge and an opportunity for economists. Many important questions need to be addressed, such as under what conditions and with what instruments (*e.g.*, MPAs, individual fishing quotas) will spatially explicit management enhance marine conservation and promote sustainable fishing practices? To explore spatial-economic phenomena in the marine environment, resource economists will need to develop new analytical approaches and adapt existing methodologies. Using this new and refurbished set of tools, it will be possible to evaluate the institutions and policies that will lead to efficient use of marine resources.

The articles in this issue explore a number of policy issues relating to spatial fishery management with a particular focus on MPAs. They utilize a wide variety of methodologies to evaluate spatial-economic issues in fishery management including: numerical bioeconomic metapopulation models (Sanchirico; Dalton and Ralston; Smith and Wilen), vector autoregression (Dalton), seemingly unrelated regression (Smith and Wilen), and random utility models (Smith and Wilen; Hicks, Kirkley, and Strand; Strand; Curtis and McConnell).

The papers also explore management issues for a variety of species' characteristics and gear types. Two papers focus on sedentary species, a red sea urchin dive fishery (Smith and Wilen), and surfclam and ocean quahog stocks caught with dredges (Hicks, Kirkley, and Strand). Two papers focus on demersal species, including groundfish stocks in New England (Holland) and rockfish stocks off of California targeted by trawlers (Dalton and Ralston). Finally, two papers analyze pelagic longline fisheries, one focusing on the Hawaii longline fishery (Curtis and McConnell), and the other focusing on Atlantic and Gulf longline fisheries (Strand).

In the remainder of our introductory article, we briefly discuss the methodologies and findings for each article.

A Summary of the Issue

"Spatial Management of Fisheries" by James Wilen leads off the issue with a discussion of the reasons for and implications of the increasing availability and use of information about spatial phenomena in marine systems. Wilen notes that recognition of the importance of space in marine systems is opening up an entire suite of research questions for economists. Bioeconomic models and management instruments based on large, spatially homogeneous fish stocks are being replaced by metapopulation models that incorporate a rich array of linkages defined over multiple spatial and temporal scales.[2] This change is driven by advances in

[1] These ideas are discussed in the Pew Oceans Commissions Report released in June of 2003 (available from www.pewoceans.org).

[2] Current large research projects, such as Census of Marine Life (www.coml.org), Partnership for Interdisciplinary Studies on Coastal Oceans (www.piscoweb.org), and Integrated Sustained Ocean Observing system (www.oceans.us) will continue to advance our understanding of how marine systems function. The functioning of marine ecosystems is complex, however, and as one marine scientist said comparing the state of marine science to climatology and meteorology, "we can predict the climate, but we still don't know enough to predict the weather."

oceanography and marine biology that have shown the importance of spatial patchiness and connectivity for both large- and small-scale marine processes. Not surprisingly, these same advances in technology and knowledge are improving fishermen's ability to find and target fish. Therefore, as Wilen explains, this progress represents both an opportunity to increase the net value derived from fisheries and a challenge to economists and fishery managers to develop analytical tools and institutions that operate at finer spatial scales.

Wilen frames his discussion of this opportunity and challenge by reviewing the progress that economists have made in developing statistical methods and bioeconomic models to quantify spatial behavior of fishermen and to evaluate spatial fishery management policies. He concludes by identifying areas where additional research is needed and encourages economists to contemplate the types of policies and institutional arrangements that will facilitate efficient spatial fishery management.

Recognizing and incorporating the spatial dimension in fisheries management does not eliminate the need for policymakers to address the open-access incentives that dissipate rents in most of the world's fisheries. It does, however, change the nature of how these incentives play out and the way that rights-based approaches can be used to promote efficient and sustainable resource use. "Spatial Fishery Rights and Marine Zoning: A Discussion with Reference to Management of Marine Resources in New England" by Dan Holland discusses the potential challenges that the spatial dimension creates for "traditional" rights-based approaches to fishery management. Using groundfish and scallop fisheries in New England as examples, he discusses a variety of spatial phenomena that might limit the efficiency gains that would be achieved by individual transferable quotas (ITQ) systems or even sole ownership of these fisheries. He discusses the potential benefits and costs of creating spatially specific catch rights for fisheries and the role of marine zoning in a spatial fishery property rights regime.

Marine zoning, in the form of MPAs, is on the policy agenda around the world, touted as a tool to both conserve ocean resources and improve the productivity of fisheries. Therefore, it should come as no surprise that most of the papers in this issue investigate the economic impacts of MPAs or develop tools that can be used for that purpose. "Designing a Cost-Effective Marine Reserve Network: A Bioeconomic Metapopulation Analysis" by James Sanchirico undertakes a simulation analysis to investigate the inherent bioeconomic tradeoffs associated with cost-effective designs of marine reserve networks. A nine-patch bioeconomic metapopulation model is used to analyze the optimal design of reserve networks in a licensed, limited-entry fishery where the effects of reserves are measured by changes in the returns to fishing post-reserve creation. The model depicts a regulator who maximizes the present value of sustainable fishery-wide rents by choosing the optimal level of aggregate effort and by deciding whether to prohibit fishing in any given patch. The model, therefore, is consistent with the traditional scope of fishery management, where regulations on fishing effort are applied over large areas.

Sanchirico finds that the types and degree of connectivity and the bioeconomic characteristics of the neighboring patches of the closed areas influence the effect the reserve has on fishery rents and consequently on the most cost-effective placement of a reserve. Under special conditions and when there are post-reserve increases in biological productivity, he shows that maximizing aggregate sustainable rents can require closing a portion of the fishable habitat. Furthermore, he compares results between an open-access fishery with reserves to a limited-entry fishery with no reserves and finds that implementing a more rationalized management system can result in larger biological gains than the gains from closing multiple subpopulations under open access.

"The California Rockfish Conservation Area and Groundfish Trawlers at Moss Landing Harbor" by Michael Dalton and Stephen Ralston analyzes the effect of the creation of the California Rockfish Conservation Area (CRCA) on Moss Landing Harbor groundfish trawlers. The objective of the CRCA, which prohibits trawling within its boundaries, is to rebuild overfished groundfish stocks by eliminating fishing effort and thus reducing the bycatch of overfished species, such as bocaccio. Since bycatch rates often vary by season and fishing grounds, the ability to achieve rebuilding goals will depend upon the bycatch rates outside the closure, which, in turn, hinge upon the extent to which spatial and temporal effort shifts occur as a result of the closure. A spatially explicit, two-patch bioeconomic model is parameterized using micro-level data and includes linear stock dynamics, ex-vessel prices, climate, and the costs of vessel crowding and movement.

Dalton and Ralston show that, for the Moss Landing groundfish trawlers, the marginal costs imposed by crowding externalities and the biological rates of stock productivity are the most significant factors to consider when evaluating the effectiveness of a spatial management policy. In addition, results from a Granger causality test indicate that ex-vessel prices drive fishing effort in this fishery. This demonstrates unequivocally the central role economics must play in managing marine resources.

The papers in this issue are consistent in their recommendations that any serious policy analysis of spatial management approaches requires understanding and modeling fishermen's behavior. The last four papers illustrate that fishers' responses to spatial policies can be effectively modeled at the individual level as rational economic decisions, and these models can be used to evaluate the biological and economic impacts of spatial policies. These papers also demonstrate that the structure of the behavioral models and how they are applied can significantly affect the results of a policy analysis.

"Marine Reserves with Endogenous Ports: Empirical Bioeconomics of the California Sea Urchin Fishery" by Martin Smith and James Wilen combines an empirical model of diver behavior with a metapopulation model of the northern California red sea urchin to analyze the bioeconomic effects of marine reserves. The behavioral model incorporated in the simulation includes daily choices of whether and where to fish as well as the choice of home port, an approach that allows simulation of both a short- and long-run behavioral response to changes induced by marine reserve formation. An implication of the more elastic effort response associated with port and region switching is that effort responds more quickly to postreserve conditions. In the short run, Smith and Wilen find that this leads to even more exploitation of nearby open patches. The redistribution of effort mitigates some of the immediate costs of the closure, but it ultimately puts more exploitation pressure on the open areas, which can prolong the transition to the steady state.

Smith and Wilen's findings cast further doubt, at least for the California red sea urchin fishery, that marine reserves will generate long-run harvest benefits. More generally, they derive conclusions that are substantially at odds with a biological model that depicts harvester behavior as unresponsive to economic opportunities over time and space.

While there is a great deal of uncertainty and controversy over the long-run impacts of marine reserves and MPAs on fisheries, it is likely that they will impose at least short-term costs on fishers that are excluded from the areas where they previously had fished. "Short-run Welfare Losses from Essential Fish Habitat Designations for the Surfclam and Ocean Quahog Fisheries" by Robert Hicks, James Kirkley, and Ivar Strand presents an assessment of the short-term welfare losses of closing specific areas of EFH to the middle Atlantic surfclam and ocean quahog fisheries. The research combines GIS analysis of observed fishing choices with a random utility model of fishing location choice to evaluate the individual losses in welfare suffered by fishers prevented from fishing in the closed areas. The spatial model of fishing behavior incorporates congestion and information effects, and this requires integrating the effects of other fishers' choices into the individual's choice model. Because location choices are interdependent, prediction of post-closure effort distribution and the welfare losses associated with it requires an iterative approach. Choice probabilities are predicted, and the explanatory variables of the utility function are recalculated iteratively until choice probabilities stabilize.

Hicks, Kirkley, and Strand find that short-run welfare losses for fishers can be quite large, but longer-term impacts could be dampened if the fleet moves to different ports or fisheries in an effort to lessen the impacts of the restrictive area closures. Research shows that the costs of closures vary greatly across individuals. The authors identify portions of the fleet whose spatial choice set was closed completely by two of the EFH closures evaluated.

Spatial choices require spatial information. For example, random utility models of fishery location choice require the researcher to characterize conditions at all of the relevant fishing sites and make assumptions about how information is generated and shared amongst participants in the fishery. "Incorporating Information and Expectations in Fishermen's Spatial Decisions" by Rita Curtis and Ted McConnell tackles the difficult issue of how fishermen collect information in an effort to make better location choice decisions and how this can be incorporated into spatial models of fishing.

Curtis and McConnell test three different information scenarios. One model assumes full updating at any point in the cruise, which assumes that the fleet is sharing all information, and another assumes that fishermen start the cruise with a set of information that is not augmented during the cruise. Finally, they consider a mixed updating model that assumes fleet information is available before departure and updating occurs, but it is based only on the fisherman's own activity. They find that the model with no information updating during the trip, which is the most restrictive of the three information scenarios, outperformed the model with continuously updated information generated by the entire fleet. The mixed information model performed the best and is consistent with limited information sharing across participants in the Hawaii longline fishery. Importantly, they showed that there is a significant divergence in welfare estimates among the three models when a fishery closure was simulated.

Another potentially important factor in fisher location choice is the individual's willingness to bear financial risk associated with fishing in areas with higher variability in expected returns. "Spatial Heterogeneity in Risk Preferences in the Atlantic and Gulf of Mexico Pelagic Longline Fishery" by Ivar Strand provides insight into how preference aggregation (by restricting parameter estimates across groups of fishermen) can lead to very different parameter estimates and welfare changes associated with spatial closures. Typically, researchers estimate a preference function for a representative fisherman that is used to characterize how fishermen throughout the fishery make tradeoffs to maximize their expected utility (if risk averse) or expected profits (if risk neutral, or for small-scale lotteries). Strand groups fishermen based on their home ports and identifies heterogeneity across groups in their willingness to trade off higher expected profits against higher profits at different fishing sites.

Strand's results suggest that performing policy analysis on the basis of aggregate models of spatial fishing is likely to generate inaccurate conclusions when there is heterogeneity among groups of fishermen. Furthermore, when the degree of heterogeneity is not trivial, aggregate models can be biased (he finds that welfare measures can diverge by as much as a factor of 10). Another implication of the research relates to how estimates from one part of a fishery can be transferred to other parts when significant heterogeneity exists across participants. Strand's results suggest that a transfer approach even within the same fishery is not appropriate. Finally, the findings should cause managers and economists to reconsider whether standard fishery-wide policies are the most efficient way to manage fisheries.

The articles in this issue build on a quickly growing literature that is just beginning to develop the ideas and methodologies needed to effectively incorporate space into marine resource economics. Not surprisingly, introducing space into bioeconomic models and microeconomic behavioral models of fishermen greatly complicates the task of undertaking *ex ante* and *ex post* policy analysis. But continued progress is important if economists wish to maintain a constructive presence in the increasingly 'spatialized' field of marine resource management and if society is to manage living marine resources for its greatest benefit.