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# An empirical analysis of the economic value of ocean space associated with commercial fishing

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ABSTRACT

Understanding the economic value of ocean space is critical for implementing marine spatial planning (MSP). Empirical data from 1999 to 2008 are compiled on the economic values arising from commercial fishing in the Gulf of Maine and adjacent areas. The data are analyzed to characterize factors affecting the spatial and temporal distribution of measures of economic productivity and fishing effort. The analysis consisted of four components: (1) estimation of net revenue at the 10-min square level by season and gear; (2) assessment of variability for catch revenue and catch per unit effort; (3) mapping net revenue and variability in the study area; and (4) estimation of interactions among catch, effort, season, and gear type. The results indicated that, at each location, average fishing efforts exhibited a positive response to increases in expected revenues and a negative response to variability in revenues. Most of the variability in catch revenue can be explained by changes in fishing effort, implying that the spatial patterns of fishery resources are relatively stable at the 10-min square level. An important conclusion is that a spatial scale of at least the 10-min square is appropriate for undertaking MSP involving allocations of commercial fisheries.


## 1. Introduction

With growing coastal populations and associated economic activities, the coastal ocean is becoming more crowded. There are many competing demands for ocean space. Marine spatial planning (MSP) is a process for improving the management of coastal and marine resources in order to promote their sustainable development. The implementation of MSP holds the promise of achieving healthy and resilient marine ecosystems that can support “sustainable, safe, secure, efficient, and productive” human uses [1,2]. In the US Northeast Region (Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut), a Northeast Regional Planning Body and the Northeast Regional Ocean Council now are seeking to advance MSP in association with federal and state agencies, other regional organizations, scientists, and stakeholders. In order to carry out MSP, ecological, social, and economic data and descriptions of ecosystem stocks and flows and existing and potential future human uses will provide the necessary inputs for undertaking analyses of tradeoffs. Tradeoff analyses are the essential building blocks for optimizing the net social benefits from different ocean uses in the planning area e.g., [3].

An economic tradeoff analysis for ocean use decisions would involve comparing resource rents (modeled here as net revenues or quasi-rents) arising from alternative use options. For example, say that a specific offshore area currently is used for commercial fishing, and a wind farm has been proposed for the same area. A tradeoff analysis would involve comparing rents from the two uses, and it may make economic sense to allow the development of the wind farm only if the rents from energy production are greater than those from commercial fishing. Thus, to facilitate the implementation of MSP, a careful assessment of the economic values of existing and proposed ocean uses and their spatial distributions is required. Given the heterogeneity of the distributions of marine resources, their uses, and environmental features, and ecological processes, an important question exists about the most appropriate scale at which to analyze tradeoffs. The question of scale is tractable for many theoretical studies, but it may be constrained in practice by data availability and legal restrictions.

MSP has received much recent attention in the theoretical and policy literatures [4,5]. Unfortunately, examples demonstrating its benefits in actual practice are still rare, with most analysts pointing to the interesting, but extraordinary – and therefore difficult to generalize – case of the management of Australia’s Great Barrier Reef [6]. Rassweiler et al. [7] analyze a case limited to the spatial management among several commercial fisheries, involving detailed habitat maps and larval dispersions influenced by ocean currents. The authors find that, depending upon the values of the parameters controlling fish stocks and the behavior governing fishermen, explicit spatial management can be profitable. Even so, the authors recognize that a modeling approach to their study is needed, given limitations on empirical measurements of fishery yields and profits. Their example highlights a question of the need to determine a *practical* spatial scale for implementing MSP.

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Crowder et al. [8] provide evidence that many failures of ocean governance are the consequence of jurisdictional boundaries that are too small or too large or human institutional "rhythms" that are too fast or too slow. The authors argue that such problems of spatial and temporal governance "mismatches" could be addressed by MSP as carried out through comprehensive ocean zoning. The authors support the idea of matching management programs to oceanographic features, especially to the geographic distributions and dynamics of biotic communities.

Douvere [5] suggests that marine spatial planning is particularly appropriate in ocean areas where the spatial and temporal overlaps of a wide variety of human activities may lead to conflicts. Such conflicts can occur between users, but spatial planning is especially important in cases where the essential conflict is between users and the environment. Among the user-environment conflicts that could be managed more appropriately with MSP, the author cites over-fishing and the loss and destruction of fisheries habitat. By definition, MSP reflects the basic heterogeneity of marine ecosystems, allowing management decisions to be tailored to the appropriate scale of the problem, leading potentially to more efficient resource uses or conservation. In fact, the author believes that all policies and management strategies aimed at regulating human uses of marine ecosystems have relevant spatial and temporal dimensions.

Halpern et al. [9] promote ocean zoning as an application of MSP, particularly where interactions among human uses or the cumulative impacts of individual uses increase the risks of exceeding ecological thresholds. These thresholds are boundaries beyond which the provision of ecosystem services may be markedly diminished. Understanding the risks of threshold exceedance requires understanding the spatial and temporal dimensions of human activities and the relevant ecosystems in which they occur. Mapping spatial (and temporal) ecosystem heterogeneity could lead to opportunities to plan for and zone human activities to optimize the delivery of ecosystem services. The authors argue that the key is to recognize and plan for human uses or conservation at the appropriate scale.

There are a number of hypothetical simulation studies that are now under development demonstrating the possible benefits of MSP. Many of these recognize the critical importance of the choice of spatial scale. Lester et al. [3] demonstrate how MSP-type tradeoff analyses could be undertaken for a spatially heterogeneous case of fish production, dispersal, harvest, and profits. While abstracting from the institutional aspects that might affect profit levels, the authors demonstrate that, depending upon parameterization, the optimal spatial patterns of commercial harvests involve a significant portion of areas to be set aside as no-take fishery reserves. The authors further show how a tradeoff among a commercial crab fishery, a wave energy facility, and coastal real estate values off the central coast of California might be assessed so that the wave energy facility could be sited optimally. White et al. [10] simulate tradeoffs among ecosystem services provided by commercial fisheries, whale-watching, and wind energy off the coast of Massachusetts. These authors show, again using a simulation approach in which fishery patches are modeled at the scale of 4 $km^2$, that economic gains obtain through MSP when compared with a form of single-sector management. They hypothesize that the benefits of MSP are increasing in the number of management strategies, the area to be allocated to wind energy, and the scale of the management area (i.e., with respect to the latter, "…MSP will create the greatest benefits when done at [an]… ecosystem scale…").

In contrast with the mostly theoretical or simulation approaches taken by other authors, this paper focuses on whether commercial fisheries data are available at temporal and spatial scales appropriate for MSP purposes. An empirical analysis of the economic values of commercial fishing in the Gulf of Maine and adjacent areas is developed. Monthly data on catch revenues and fishing effort by gear during the 10-year period from 1999 to 2008 are examined. The available data sets a lower bound on the spatial scale, restricting the analysis to areas bounded by 10-min squares.[1] Analysis of the data focuses on the question of whether monthly commercial fisheries catch and effort data at the 10-min square level could potentially be useful for MSP-type tradeoff analyses in the Gulf of Maine and Georges Bank.

## 2. Methods

This analysis consists of four components: (1) estimation of net revenue at the 10-min square level by season and gear; (2) assessment of variability for catch revenue and catch per unit effort (CPUE); (3) mapping the net revenue and variability; and (4) estimation of statistical models that capture interactions among catch, effort, season, and gear type.

The economic value to commercial fishing of a unit ocean space (i.e., a 10-min square) is the net revenue generated from fishing operations in the area. Because net revenue is primarily affected by the condition of fishery stocks, which, in turn, is influenced by resource management institutions [11], it is important to recognize that the economic value estimated in this study is conditioned on current management institutions. The economic value potentially achievable under socially optimal management is not analyzed here.

### 2.1. Calculation of net revenue from commercial fishing

The commercial fishing industry in New England involves vessels of different sizes with different gears to harvest many different species. A good measure of the importance of a specific offshore area to the fishing industry must capture the variations in both outputs and inputs. For example, the total catch quantity from the area would fail to capture the value differences across species, and the total days fished in the area cannot accurately gauge the effective fishing efforts by vessels of different sizes and gear types. Thus, net revenue is used to measure the economic importance of an area to fishing.

The conceptual framework for calculating the net revenue from commercial fishing is straightforward (Fig. 1). First, catch and effort data are compiled for each spatial location ($k$) and time period ($t$). The catch and effort data are then combined with relevant price and cost information to estimate the total revenue and cost at $k$ and $t$.

The total gross revenue $R$ at location $k$ and time $t$ is

$$R_{k,t} = \sum_{s} P_{s,t} Q_{s,k,t} \tag{1}$$

where $P_{s,t}$ is the price (in dollars per pound) of species $s$ at $t$, and $Q_{s,k,t}$ is the catch (in pounds) of species $s$, at location $k$ and time $t$.

The total cost $C$ at location $k$ and time $t$ is

$$C_{k,t} = \sum_{g} \sum_{n} W_{g,n} D_{g,n,k,t} \tag{2}$$

where $W_{g,n}$ is the unit cost (in dollars per day absent) of gear type $g$ and vessel ton class $n$, and $D_{g,n,k,t}$ is the number of days absent of gear type $g$, vessel ton class $n$, at location $k$ and time $t$.

Finally, location- and time-specific net revenue is obtained by subtracting the total cost from the total revenue. The net revenue is $R_{k,t} - C_{k,t}$.

### 2.2. Value-based CPUE

In classical bioeconomic analysis, the quantity of fish harvested ($h$) is a function of a catchability coefficient ($q$), fishing effort ($E$), and the fish stock size ($x$): $h = qEx$ [12]. The corresponding catch per

[1] A grid of 10-min longitude by 10-min latitude (approximately 75 square nautical miles).