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Short-run Welfare Losses from Essential Fish Habitat Designations for the Surfclam and Ocean Quahog Fisheries

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Abstract *In this paper, we present a spatial model of fishing that can be used to assess some of the economic welfare losses to producers from setting aside essential fish habitat (EFH) areas. The paper demonstrates how spatially explicit behavioral models of fishing are estimated, how these models can be used to measure welfare losses to fishermen, and how these models can then, in turn, be used to simulate fishing behavior. In developing the spatial model of fishing behavior, the work incorporates ideas of congestion and information effects, and we show a modification of standard welfare measures that accounts for these spillover effects. Using this methodology, these effects are traced through to the policy simulations, where we demonstrate how these welfare and predicted shares need to be modified to account for spillover effects from fleet activity.*

Key words Random utility model, spatial choice, commercial fishing, congestion externalities.

JEL Classification Codes Q22, Q28.

Introduction

The Sustainable Fisheries Act of 1996, Public Law 104-267, amended the Magnuson-Stevens Fisheries Conservation and Management Act to establish new requirements for protecting or restoring essential fish habitat (EFH). Under the Act, EFH is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (Magnuson-Stevens Fisheries Conservation and Management Act, section 3). An EFH consultation with NOAA Fisheries is required of all federal agencies undertaking, permitting, or funding activities that may adversely affect EFH, regardless of its location.

Under the Sustainable Fisheries Act, all federal fishery management councils

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must take appropriate steps to minimize the potentially adverse impacts of fishing on EFH. This may be accomplished by imposing management measures including, but not limited to, fishing equipment restrictions, time/area closures, and harvest limits. Assessing the potential economic ramifications of regulatory options designed to protect or restore EFH may be extremely complicated. The major complication is the absence of information relating the quality or condition of EFH to future fishing activities. The dynamics and interactions between EFH and future resource abundance, availability, and levels are generally unknown.

Beginning in 2000, the Mid-Atlantic Fishery Management Council (the Council) became concerned with EFH issues relating to the surfclam and ocean quahog fisheries. The Council was preparing Amendment 13, which was to change the quota levels for the fisheries. As per the requirements of the Sustainable Fisheries Act, the Council proposed several EFH areas, and drafted four potential closure options to protect EFH. The draft Regulatory Impact Review for establishing the EFH, however, was rejected because the Council failed to adequately consider the possible economic ramifications that might result from the four proposed closed areas, as well as the option of no change or the status quo.

In this paper, we investigate how a spatial model of fishing can be used to assess some of the economic welfare losses to producers from setting aside EFH areas. Since no solid evidence exists concerning the biological effects of EFH designations, we present a limited assessment of the potential, short-run economic ramifications of regulatory options—closed areas—designed to minimize the adverse effects of surfclam (*Spisula solidissima*) and ocean quahog (*Arctica islandica*) fishing on EFH. It is important to recognize this limitation because a short-run analysis is likely to predict only negative consequences of options to protect EFH (*e.g.*, losses in producer welfare), when in fact, there may be substantial gains in net benefits in the long run.

The paper demonstrates how spatially explicit behavioral models of fishing are estimated, how these models can be used to measure welfare losses to fishermen, and how these models can then, in turn, be used to simulate fishing behavior. In developing the spatial model of fishing behavior, the work incorporates ideas of congestion and information effects, and we show how standard welfare measures must be modified to account for these spillover effects. Using this methodology, these effects are traced through to the policy simulations. While the use of proxy measures for congestion and information has been done before, we demonstrate how these site-specific attributes affect welfare and policy simulations. We also identify those portions of the fleet most likely to change their homeport due to the EFH regulations.

The Surfclam and Ocean Quahog Fisheries

Resource Distribution and the Commercial Fisheries

Surfclams and ocean quahogs are distributed in the Northwest Atlantic from the Gulf of Saint Lawrence to Cape Hatteras (Mid-Atlantic Fishery Management Council 1998). Ocean quahogs, however, are also distributed from the Bay of Cadiz of Southwest Spain intermittently across the North Atlantic. Both species are relatively long lived—surfclams to about 35 years of age and ocean quahogs to over 100 years of age. The ocean quahog is recognized as the longest living bivalve in the world.

The primary commercial gear used to harvest both species is the dredge. Surfclam and ocean quahog vessels are generally designed and constructed exclusively for harvesting surfclams and ocean quahogs, and thus, they cannot be easily reconfigured to permit fishing in other fisheries. Since 1994, most of the landings of surfclams from the Exclusive Economic Zone (EEZ) have been taken from the Mid-Atlantic region. Landings of ocean quahogs have been about evenly distributed between the New England and Mid-Atlantic ranges. Recently, however, landings from the Mid-Atlantic region have generally been higher than landings from the New England region. Prior to 1990, both surfclams and ocean quahogs were also harvested from Georges Bank. Since 1990, there have been no reported landings from east of 69°W longitude because Georges Bank has been closed due to the risk of paralytic shellfish poisoning.

There are actually three distinct fisheries. There is the surfclam fishery, which is primarily conducted in the Mid-Atlantic region. There is an ocean quahog fishery, which is conducted in both the New England and Mid-Atlantic regions. There is also a Maine and Rhode Island fishery for mahoganies, which are also ocean quahogs. The Maine and Rhode Island fisheries land smaller quahogs for the live market; these clams generally compete with the inshore hard clam or quahog, which often may be sold as topnecks, little necks, and cherrystone clams.

Product Markets, Pricing, and Production

The primary use of surfclams has been in the "strip market" to produce fried clams. In recent years, however, surfclams have been increasingly used in chopped or ground form for other products (*e.g.*, high-quality soups and chowders). In contrast, ocean quahogs are generally viewed as a lower-valued product; the primary uses of quahogs have been soups, chowders, and white sauces. Quahog meat has a sharper taste and darker color than surfclams, which is why they have not been used in the more lucrative strip market. In 2000, the average ex-vessel price for surfclams was approximately $8.39 per bushel, while the average annual price for ocean quahogs was about $4.30 per bushel. The mahoganies typically command a much higher price. In 2000, the average ex-vessel price for mahoganies was $27.44 per bushel.

In 1991, there were 121 vessels in the surfclam and ocean quahog fisheries; 47 of the 121 vessels landed both surfclams and quahogs. In 2000, there were 82 vessels in the surfclam and quahog fisheries, and only 12 vessels landed both surfclams and ocean quahogs. During the 1980s and early 1990s, vessels tended to jointly exploit surfclams and ocean quahogs. Since 1995, the percentage of the fleet exploiting both species has dropped to below 30%. The primary reason for the contraction was probably good management.

Management of the Fisheries

Management of the fisheries is under the primary responsibility of the Council. Prior to 1990, the fisheries were regulated by a series of command and control regulations (*e.g.*, annual and quarterly quotas, minimum sizes, gear and effort restrictions, and limited entry). In 1990, the Council established an individual transferable quota (ITQ) program to manage the fisheries. Permits and ITQs pertain only to surfclams and ocean quahogs; they do not permit harvesting any other species. In addition, surfclam and quahog vessels are designed such that, without very expensive reconfigurations, they cannot harvest other species. The original ITQ program excluded the Maine quahog fishery because the Maine fishery did not extend to the EEZ at that time. It was subsequently discovered, however, that the Maine fishery was moving into the EEZ, and in 1998, the Council implemented an ITQ program for the Maine fishery.

Spatial Model of Fishing

A Framework for Assessing Short-run Welfare Losses

The usage of closed areas to protect EFH has the potential to cause substantial reductions in production or landings, ex-vessel revenues, profits, and producer welfare. With closed areas, it would be expected that fishing operators would reallocate their effort spatially in order to minimize the impacts of a closure. It would also be expected that pre-EFH closed area strategies reflected decisions representing optimal spatial choices. The need for operators to change fishing areas, thus, would be expected to reduce producer welfare in the short run. In the section, we present a framework for analyzing the potential short-run welfare losses associated with the various spatial closures considered by the council.

Spatial Choice, Congestion, and Assessing Welfare Losses

There is growing literature on estimating the potential economic benefits and costs of area management (Eales and Wilen 1986; Dupont 1993; Curtis 1999; Holland and Sutinen 1999, 2000; Curtis and Hicks 2000; Smith 2002; Wilen *et al.* 2002; and Smith and Wilen 2003 a,b). The analytical framework we offer, therefore, adapts this methodology to analyze changes to producer welfare losses from EFH designations. We initially develop a spatial choice model, which describes how fishermen choose fishing areas, to assess the losses in short-run welfare.[1]

One feature of our model is the introduction of potential congestion effects caused by concentrating fishing effort by closing certain areas of the ocean. The implication of including concentration effects in the model of commercial fishermen's spatial choice is explored particularly for the case of policy analysis and welfare measurement. The model is then used to estimate the loss in economic value to commercial fishermen associated with closing areas of the ocean.

We analyze four potential area closures proposed by the Council to protect EFH. The four EFH designated areas, however, are important not only for surfclams and ocean quahogs, but also to numerous other marine species (*e.g.*, summer flounder, sea scallops, monkfish, and American lobster). The four options, or potential closed areas, are as follows: (*i*) Option 2 proposes to prohibit clam dredging on Georges Bank east of 69°; (*ii*) Option 3 proposes to prohibit dredging east of 70°, 20 minutes; (*iii*) Option 6 prohibits dredging in the tilefish habitat areas of particular concern (HAPC), which is characterized as the depths between 250 and 1,200 feet between Cape Cod, Massachusetts, and Cape May, New Jersey; and (*iv*) Option 8 closes the western extent of the Maine quahog fishery in the EEZ.[2]

Our analysis is limited to only the surfclam and ocean quahog fleets. We do not consider the potential impacts on other fisheries. An important aspect of analyzing the potential economic ramifications of the closed area options is the determination

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[1] We remind the reader that, depending upon the ecological system, it is possible that there could be "double dividends" associated with reserve creation (Sanchirico and Wilen 2001; Holland and Brazee 1996; and Hannesson 1998), where both harvests and stocks increase. It is also possible that preserve creation does relatively little for the stock. For this fishery, there is a paucity of scientific evidence concerning the intertemporal impacts of preserve creation. Our analysis, therefore, should be thought of as a short-run examination of the costs of preserve creation.

[2] The Council originally considered eight options. Several of these were rejected early on in the process. The four considered options discussed in this paper (2, 3, 6, and 8) retain the numbering scheme suggested by the Council for the sake of comparability.

of the likely behavior of fishermen relative to selecting where to fish in the presence of spatial closures. We address the issue of area selection by developing an econometric model that relates fishing area choice to areas' expected revenues, costs, and potential congestion from other vessels.

Data and Model Development

The data used to estimate the model and conduct the economic analysis was logbook data. This data places fishermen in a 10-minute square, and provides information necessary for model specification. In particular, the logbook data provides information for characterizing historic averages by month for each area of landings per unit effort (LPUE), fishing time (TIME), the variance of area-specific net revenues (VAR), and the number of trips in the preceding 30 days (FLEET). Furthermore, the data can be used to characterize a vessel's homeport,[3] which is used as a basis to calculate distances to each area under consideration by the fisherman.

Defining fishing areas is an important step in formulating the econometric model of fishing site choice. We initially consider fishing areas to correspond to 10-minute squares because this is the common geographic scale used in data collection for the fishery. For the period 1996–2000, clam (quahog) fishermen were observed fishing in 160 (279) unique 10-minute square areas. For our estimation, we need monthly averages for LPUE, VAR, and TIME, and monthly totals for FLEET for a total of 12 x 160 (279) area-specific data points for each variable. Clearly, increasing the number of areas that must be included in the model increases the information requirements and risks spreading historical data "too thin" when trying to characterize area-specific information. For these reasons, choice areas were defined based on 30-minute squares, which decreased the number of areas relative to areas defined by 10-minute squares. The use of 30-minute square areas also increases the level of geographic aggregation in the model. We eliminated areas that were visited sparingly (or not at all) by fishermen, because it was thought that inclusion of these areas would not yield results applicable to the four closed area options.[4]

Additionally, for the clam and Mid-Atlantic quahog fisheries, a vessel's choice set was defined based upon distance from their homeport. For the clam fishery, larger vessels' (class 2 or 3) choice sets were restricted as those viable 30-minute square areas within 100 miles, while class 1 vessels were restricted to those areas within 40 miles of their port. For the Mid-Atlantic quahog fishery, class 3 vessel choice sets were restricted as those viable 30-minute square areas within 150 miles, class 2 vessels were restricted to those areas within 130 miles, and class 1 vessels were restricted to areas within 60 miles of their port. Because the Maine quahog fishery is so geographically compact, all feasible areas were within close range of homeports. These cutoff distances were determined by examining observed one-way distances in the data by vessel size. The reader should note that reducing the spatial extent of the choice set by distance may arbitrarily eliminate viable substitute areas. For a discussion on the implications of choice set boundaries on welfare measures in a recreation demand context, see Haab and Hicks (1997), Hicks and Strand (2000), Haab and Hicks (1999), and Parsons and Hauber (1998).

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[3] Because there is no clear definition of the point of departure for each trip in the logbook data, we use the port of landing (for years 1996–2000) and calculate homeport based upon plurality, since nearly all vessels ended a vast majority of trips at the same port.

[4] Sites with fewer than five trips per year, on average, for the period 1996–2000 were eliminated as an area in an attempt to ensure that results would apply to the most recent time period.

Fishing activities between 1996 and 2000, related to surfclams, ocean quahogs, and mahoganies, were widely distributed between Maine and Virginia (figures 1-3); the numbered areas in figures 1-3 pertain to 30-minute squares included in the spatial choice set. The dark areas represent a higher concentration of fishing. Based upon the rules for defining the choice set previously discussed, the surfclam, ocean quahog, and Maine quahog had on average 14.33, 21.92, and 7 areas from which fishermen in the respective fisheries could choose.

Comparing figures 1, 2, and 3 illustrates that the Maine fishery is the most geographically compact, while the Mid-Atlantic quahog fishery covers significantly more ground with major activity occurring off the coastline from Maryland to Massachusetts. The surfclam fishery, on the other hand, concentrates most of its activity off the coasts of New Jersey and Delaware.

The Council proposed four EFH areas (referred to as Options 2, 3, 6, and 8) to protect surfclams, ocean quahogs, and other species. Since the area closure definitions overlapped some 30-minute squares, we were not able to precisely match the proposed closed areas' coordinates to our definition of the spatial choice set, we chose to close the entire 30-minute square area. Where small parts of a 30-minute square area were affected by a closure (*e.g.*, the Option 6 closure is an example), an analysis of a larger closure was undertaken since our analysis assumed the entire area was off limits to fishing. Consequently, our analysis yields a worst case, or upper bound estimate of the impact of the various options on fishermen.

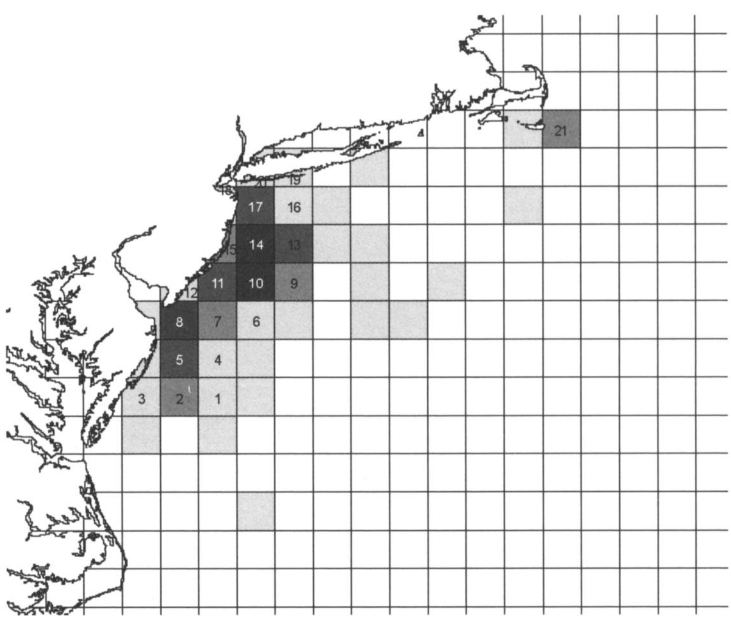

Figure 1. Clam Actual Trips (1996–2000) and Definition of Choice Set

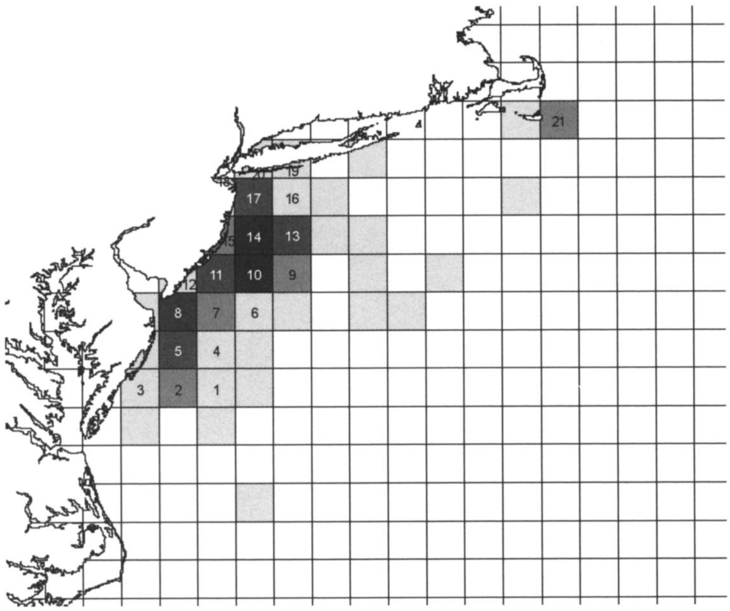

Figure 2. Quahog Actual Trips (1996–2000) and Definition of Choice Set

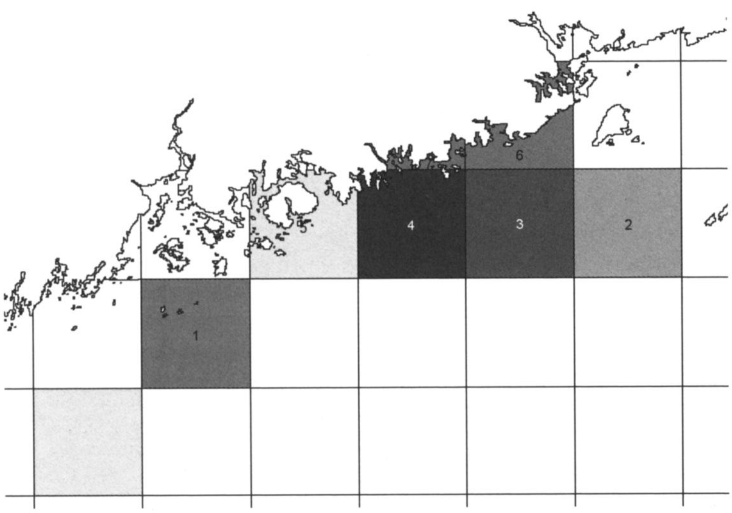

Figure 3. Maine Quahog Actual Trips (1996–2000) and Definition of Choice Set

The Spatial Choice Model

Fishermen likely choose areas based upon factors related to site profitability: the LPUE per unit time in an area, the expected length of time spent fishing (TIME), and the distance to the fishing site (DISTANCE). Furthermore, the fisherman might likely consider variability (either in terms of LPUE, TIME, or both) when comparing one area to another. Additionally, there is the possibility that some fishermen will avoid some areas because of possible congestion associated with having too many fishing boats on a given fishing ground. Consequently, fishermen are likely to examine how many boats have been or are in the area. For our analysis, we use the number of vessels (FLEET) and the number of vessels squared (FLEET2) in the area during the preceding 30 days as a proxy for congestion. Admittedly, this proxy of congestion is also likely capturing information effects. However, given a paucity of data on how fishermen share information versus avoid congestion, we feel that this provides a reasonable approach for capturing congestion at high levels of fleet activity. The challenge is to estimate a fisherman's decision rule for choosing areas that balance these area-specific factors.

The area choice model we use was initially proposed by Hanemann (1982) and adapted to fisheries by Bockstael and Opaluch (1983). The model allows for the estimation of decision rules of fishing area choice that incorporates factors important for the choice including the relative "riskiness" of different fishing areas. This is particularly useful for quantifying the tradeoffs fishermen make with respect to factors they consider when choosing one fishing area over others. In our application of Hanemann's model, fishermen are assumed to choose the best site by considering site-specific information such as LPUE, variability of profits, distance to the site, *etc.* Fishermen choose the best site from among n alternatives each having uncertain returns.

The work of Bockstael and Opaluch (1983) assumes economic decisionmakers are expected utility maximizers whose expected utility has a mean-variance functional form. Performing a Taylor series expansion of the individual's utility function around wealth at site j yields:

$$U(W_j) = U\left[W^0 + E(\pi_j)\right] + \sum_{k=1}^{\infty} \frac{\partial^k U\left[W^0 + E(\pi_j)\right]}{\partial W^k} * \frac{\left[W - W^0 - E(\pi_j)\right]^k}{k!}, \qquad (1)$$

where W^o = the fisherman's initial level of wealth, and $E(\pi_j)$ = mean net revenues at site j. By selecting a functional form, taking the expected value of this function, restricting the utility function to depend only upon the mean and variance, and subsequently parameterizing the equation to conform to a random utility framework, we derive an equation that can be estimated:

$$\underbrace{EU(W_j) = \alpha \ln\left[W^0 + E(\pi_j)\right] + \frac{\beta Var(\pi_j)}{2\left[W^0 + E(\pi_j)\right]^2} + \delta FLEET_j + \phi FLEET2_j + \varepsilon_j}_{\text{write as } v(w_j)}. \qquad (1')$$

Equation (1′) is a reduced form of how fleet size should enter the indirect utility function. Notice that the error term, ε_j, is site-specific. The fisherman then chooses site i if the site is the best place to fish out of the set of all possible fishing choices, S:

$$EU(W_i) > EU(W_j)\ \forall i, j \in S.$$

Assuming that the area-specific area terms, ε_j, are distributed as Type I Generalized Extreme Value, we can write the probability that area *i* is chosen as:

$$P(i) = \frac{e^{v(w_i)}}{\sum_{j \in S} e^{v(w_j)}}. \tag{2}$$

Using maximum likelihood techniques, we can recover the parameters α, β, δ, and ϕ and predict the redistribution of trips following closures. *A priori*, we expect $\alpha > 0$, $\beta < 0$, $\delta > 0$, and $\phi < 0$, since all things equal, anglers would choose sites with higher expected profits or lower variability. We expect that the effect of vessel activity would be positive at lower levels, since the presence of other vessels might indicate to the captain that successful fishing operations are being undertaken at an area. However, when the number of trips exceeds some threshold level, the effect of congestion is felt and fishermen are less likely to choose that alternative.

Mean profits (net of fishing and steaming travel costs) at each area were calculated by month to yield an estimate of $E(\pi_j)$. Profit levels per vessel were estimated using cost information available in McCay and Brandt (2001). From McCay and Brandt, we calculated average cost relationships for the three fisheries considered here. Specifically, it was determined that steam costs were, on average, \$6.40/mile for the surfclam fleet and \$5.52/mile for the Maine and Mid-Atlantic quahog fleets. Additionally, it was determined that dredge time for the two fleets costs approximately \$40/hour once on the fishing grounds. Our estimate of $E(\pi_j)$ for the Maine and Mid-Atlantic quahog fleet is calculated as follows:

$$E(\pi_j) = TIME(quahog)_j$$
$$* \left[PRICE(quahog) * LPUE(quahog)_j - \$40\right] - \$6.40 * \text{DISTANCE}_j.$$

For the surfclam fleet, our estimate of $E(\pi_j)$ is:

$$E(\pi_j) = TIME(surfclam)_j$$
$$* \left[PRICE(surfclam) * LPUE(surfclam)_j - \$40\right] - \$6.40 * \text{DISTANCE}_j.$$

The variables TIME (average numbers of hours fished while on the fishing grounds), PRICE (average price based upon a vessel's homeport designation), LPUE (the average catch per hour while on fishing grounds), and DISTANCE (the distance from the vessel's homeport designation to the center of the fishing ground) were calculated using historical data for each of the three fisheries for the period 1996–2000 to yield per-month averages. We calculated the variance of π_j for each month and 30-minute square area to yield $Var(\pi_j)$.

Following Hanemann (1982), the measurement of welfare changes can be accomplished via numerical methods by calculating the expected value of compensation (*C*) for a closure of certain areas in the choice set that holds expected maximum utility constant (with expectations taken over the site-specific error terms):

$$V^0\left[W^0 + E(\pi)^0, Var(\pi)^0, Fleet^0\right] = V^1\left[W^0 + E(\pi)^0 + C, Var(\pi)^0, Fleet^1\right], \tag{3}$$

where the expected maximum utility (EMAX) for a choice occasion, $V^k[W^0 + E(\pi)^0, Var(\pi)^0, Fleet^k]$, is equal to:

$$E\left[\max\left\{U\left[W^0 + E(\pi_j)^0 + C, Var(\pi_j)^0, Fleet^k\right] + \varepsilon_j, \forall j \in S^k\right\}\right].^{5,6}$$

Notice EMAX is taken over the original set of fishing alternatives S to yield V^0 and taken over only those sites remaining open after the EFH designation (S^1) to yield V^1. Therefore, C is the amount of compensation necessary after the closure of some sites to hold utility at a level as if the closures never happened. The expectations operator of the EMAX function is the researcher's expectation taken over ε_j.

The expected utility function (V^1) depends on the fleet's area choices post closure. This complicates the standard welfare analysis as typically used in applications of the RUM model, since each vessel's preferences depend on other choices in the fleet. To account for this interrelationship, we employ an iterative procedure for reallocating the fleet following a closure. The steps of this procedure are outlined below:

1. Assign initial guess for site-specific probability functions.
   a) If this is iteration number one, the guess is simply the vector π^0 using equation (2) for each area. If an area is closed, the observed trip activity is reallocated to other open areas proportionally to observed activity in the open areas.
   b) If this is not the first iteration, the vector π^1 (which is equal to π^2 from previous iteration) is used.
2. Using the guess for the site-specific probabilities, calculate the updated prediction for the expected values of FLEET and FLEET2 for each area and trip in the data.
3. Using the updated values of FLEET and FLEET2 for each area, calculate the updated predicted probability vector π^2.
4. Repeat steps 2-3 until $|\bar{\pi}^1 - \bar{\pi}^2| \leq \theta$ (For this study, θ was set at .001.).
5. Otherwise, assign the final values of FLEET and FLEET2 following the closure for each area. Calculate the final predicted choice probabilities (π).

Using the final predicted values of FLEET and FLEET2, then calculate the final estimate of V^1 that incorporates congestion and information spillover effects.

The goal of the estimation problem is to recover structural parameters of the individual's utility function that reveal information about how fishing sites are chosen. In order to implement equation (1′), we estimated vessels' initial wealth, W^0; expected profits, $E(\pi_j)$; and the variance of area-specific profits, $Var(\pi_j)$ for each area considered by the fishermen. Following Bockstael and Opaluch (1983), we approximated W^0 by the value of the vessel.[7]

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[5] To solve for C, we employ the bisection method for finding roots for a one-dimensional equation. While more efficient numerical methods may exist to find roots of an equation, we found equation (3) converged quickly.

[6] Work by McFadden (1995) and applied to recreation demand by Herriges and Kling (1999) has investigated the bias associated with calculating welfare changes using the EMAX function when the indirect utility function is nonlinear in income. We believe our approach using the EMAX function provides a reasonable approximation for the short-run welfare loss of area closures, since these papers have not investigated this bias with our functional form and most policies impose a relatively small change in individual's choice opportunities.

[7] Because of inadequate data on fishing firms' current levels of wealth, we adopt the approach of Kitts, Thunberg, and Robertson (2000), which demonstrates that the value of the vessel and gear (*i.e.*, an approximate value of wealth) is approximately equal to one year's gross stock or annual ex-vessel revenue. This relationship is assumed to apply to the clam and quahog vessels in this fishery.

Results and Policy Simulation

The results (table 1) confirm *a priori* beliefs about how fishermen balance the various factors influencing fishing site choice. Fishermen were more likely to choose sites that are more profitable (which could mean closer, less costly, or higher LPUE) or less likely to choose sites with high variability. They were also more likely to choose sites where a significant activity was occurring until the level of activity exceeded a threshold level and then they were less likely to choose sites. All results were significant at the 5% level of significance, and the model likelihood ratio test statistic (versus a model where all parameters are equal to zero) indicates that the model is preferred at the 5% level of significance. Since one of the primary uses of the model will be for predicting where fishermen will fish once area closures are enacted using equation (2), we also construct a goodness-of-fit measure by calculating the percentage of observations where the model predicts the actual choices of individuals (based upon the observation with the highest calculated probability). Results for this statistic show that relative to a naïve prediction of the inverse of the number of choices in the choice set, each choice model predicts choices well.

Short-run Welfare Losses

In order to understand the impact of the potential EFH regulations on each of the three fisheries, consider table 2. First, the table illustrates some variability in landings and revenues during the years 1996–2000. We construct a status-quo or reference level of permits (number of boats), trips, landings, revenues, and prices, by taking the fleet average for the years 1996–2000. Rather than choose the latest year in the data (2000), we felt that defining the fleet baseline level over a five-year time period was a reasonable way to eliminate noise that might cause year-to-year fluctuations that are not constructive to the analysis. The table also illustrates, in the final four rows, that fleet activity for each of the EFH closure areas is minimal in comparison to overall totals.

Of the four options, only Option 3 has potentially catastrophic effects, which pertain to the Maine quahog fishery, because the entire fishing area for this fleet is

Table 1
Site Choice Model Parameter Estimates (t-statistics reported in parenthesis)

Parameter	Clams	Quahogs	ME Quahogs
α	11.23	25.05	30.35
	(19.01)	(29.29)	(11.23)
β	–682.72	–50.77	–95.28
	(14.13)	(3.67)	(4.32)
δ	0.11	0.16	0.05
	(84.67)	(69.96)	(57.36)
φ	–0.00071	–0.0018	–0.00011
	(52.11)	(37.97)	(42.04)
χ^2 (all parms=0)	21,843.22	16,673.36	18,738.66
Average # Choices	14.33	21.92	7
% Predicted Correctly	37.74	25.74	74.01

* All parameters significant at the 5% level.

Table 2
Summary of Activity, Landings, Prices, and Revenues Associated with Each Policy Option Relative to Baseline Quotas (Option Summaries Based on Yearly Averages 1996–2000)

	Permits			Trips			Landings			Revenues			Prices		
Option	Surfclams	Quahogs	ME Quahogs	Surfclams	Quahogs	ME Quahogs	Surfclams	Quahogs	ME Quahogs	Surfclams	Quahogs	ME Quahogs	Surfclams	Quahogs	ME Quahogs
1996	34	36	25	2,178	2,545	1,375	2,569,319	4,391,428	47,025	27,705,187	19,934,634	1,494,332	$10.78	$4.54	$31.78
1997	33	31	34	2,119	2,294	1,949	2,413,575	4,279,059	72,706	25,931,856	19,093,240	2,046,248	$10.74	$4.46	$28.14
1998	31	24	39	2,076	1,957	1,823	2,365,374	3,897,487	72,466	21,347,979	17,378,545	2,005,194	$9.03	$4.46	$27.67
1999	33	23	38	2,155	2,078	2,084	2,537,879	3,770,288	94,175	22,074,244	16,438,214	2,683,811	$8.70	$4.36	$28.50
2000	31	29	34	2,041	1,811	2,259	2,561,021	3,160,649	120,767	21,771,814	13,654,772	3,305,575	$8.50	$4.32	$27.37
Status Quo (96-00 avg)	32	29	34	2,114	2,137	1,898	2,489,434	3,899,782	81,428	23,766,216	17,299,881	2,307,032	$9.55	$4.44	$28.33
Option 2 area	0	2	0	0	0	0	0	397	0	0	1,686	0	N/A	$4.25	N/A
Option 3 area	2	10	34	21	323	1,898	7,568	711,644	81,428	105,706	3,079,358	2,307,032	$13.97	$4.33	$28.33
Option 6 area	4	17	0	24	461	0	33,038	835,709	0	317,313	3,743,184	0	$9.60	$4.48	N/A
Option 8 area	0	0	1	0	0	14	0	0	639	0	0	17,231	N/A	N/A	$26.95

closed by this option. Options 3 and 6 have the potential to impact the quahog fishery, since a significant number of vessels, trips, and revenues are derived from the offshore areas impacted by Option 3. For the clam fishery, Options 3 and 6 will impact fishing activities, but since the majority of activity does not occur so far offshore, the impact is likely to be much smaller than the quahog fishery. Finally, Option 8, which has ramifications only for the Maine quahog fishery, has only a minimal impact on the Maine quahog or mahogany fishery. The 1996–2000 average annual number of trips to the areas related to Option 8 equaled only 14, and thus, the impacts of this option would be expected to be small.

Analyzing the effect of closures by looking at observed activity in areas does provide context for who will be affected and how important EFH areas are for historic fishing grounds. This type of analysis ignores, however, how fishermen might respond to area closures. It is unlikely that they would completely stop fishing during times usually spent fishing in EFH areas. Rather, it is more likely that they will respond by shifting their effort to other areas. To model these types of reactions in the context of our estimated behavioral parameters and model presented above requires some modification from the standard welfare changes analysis. Notice that the site-specific expected utility function (equation 1′) includes the variables FLEET and $FLEET^2$, which are intended to capture the effect of other vessels' choices on the current choice for a vessel. As areas are closed due to EFH designations, the fleet will re-optimize their location choices in order to maximize individual profits given regulatory constraints. Consequently, the standard welfare analysis (in which other decisionmakers' choices do not affect a person's current choice) must be amended to accommodate the effect of information effects or crowding. In order to model the welfare effects and choice probabilities, we conduct the iterative analysis as described in the preceding section.

We use the model to estimate policy-relevant outputs that describe impacts and likely responses from the EFH closures being considered. Changes in welfare were calculated using equation (3). First, we calculate C, the welfare measure that equates post-closure with the baseline pre-closure level of expected utility. This measure can be thought of as an at-the-dock payment a fisherman facing the area closures would need to be paid to compensate for the area closure. This payment would compensate him for changing expenses relating to travel and fishing at a site, a change in LPUE and variability of profits, and changing conditions with regard to fleet congestion and information.

Consequently, the measure embodies all of the factors underlying the decision rule presented in equation 1′. For each of the policies, we calculate C per trip (table 3). First, Option 2 does not impact the spatial choice set of any of the three fisheries, so there are no appreciable welfare changes to measure. Option 3 completely closes the Maine quahog fishery and has some implications for the quahog fishery, since a portion of its activity does occur a fair distance from shore. The clam fishery has small measurable impacts since fishing grounds (for the area-choice analysis) are mostly west of the cutoff line. The exception is for boats steaming out of the ports in the northern range of the clam fishery (Rhode Island- and Massachusetts-based vessels). These vessels are affected more than vessels based out of New Jersey or points south. Option 6, which closes a significant area in the offshore areas of the Mid-Atlantic region, has significant impacts (relative to per-trip revenues) on the quahog fishery and, to a lesser degree, the clam fishery. Finally Option 8, has significant impacts on the Maine quahog fishery, but has no effect on either of the Mid-Atlantic fisheries.

It is important to note that even though most of these options had minor impacts on fleet activity based upon historical fishing patterns, C compensates all fishermen for the EFH closures as long as they have some probability of choosing an affected

Table 3
Mean Welfare Change Per Trip

Policy	Clams	Quahogs	ME Quahogs
Option 1: Status Quo	No Impact	No Impact	No Impact
Option 2: Close Georges Bank	No Impact	No Impact	No Impact
Option 3: Close waters east of 70d20m	$2.01[a]	$1,064.89	Complete Closure of Fishery[b]
Option 6: Close Tilefish Area	$70.89	$2,636.62	No Impact
Option 8: West of ME Zone 1	No Impact	No Impact	$888.06
Average Revenue per Trip	$10,908.94	$8,088.59	$1,215.88

Notes:
[a] For a portion of observations (where port state was either Massachusetts or Rhode Island, Option 3 closed all of their feasible fishing options. For these vessels, no welfare effect could be calculated.
[b] Because this option closes all fishing grounds for the Maine quahog fishery, it is not mathematically possible to calculate a welfare change for this policy.

fishing site. In particular, this is important for the Maine Option 8 closure. Even though relatively little activity is observed in EFH areas during the period 1996–2000, the spatial extent of the fishery is quite small, and the closure affects an area where a large number of fishermen have a relatively high predicted probability of choosing.

Using equation (2), we also predict likely vessel area choices resulting from the closures. For quahogs, a significant portion of the reallocated effort occurs just west of the closure area off the coast of southern Massachusetts and Rhode Island. The clam fishery, largely unaffected, is predicted to maintain effort in the Mid-Atlantic region on historical fishing grounds. Option 6 had an impact on the quahog fishery because many of the Mid-Atlantic offshore areas were no longer available to fishermen. The predicted response is to move activity from the offshore areas inshore, either northward toward Long Island and Rhode Island or westward toward New Jersey. For clam fishermen, activity is predicted to concentrate in the nearer shore areas off of New Jersey. Option 8, the closure of the western extent of the Maine quahog fishery, is predicted to result in a higher concentration of vessels in the primary fishing grounds.[8]

Table 4 contains an estimate of the total welfare impact for each of the EFH closures under the baseline quota levels assuming no changes in trips. These numbers demonstrate the upper bound losses associated with imposing EFH restrictions. The clam fishery is affected the least across all EFH options relative to the other fisheries considered here. Quahogs (for Options 3 and 6) suffer a significant loss when compared to total fleet revenues. Option 8 also significantly impacts the Maine fishery with an economic welfare loss associated with the area closure to be a significant portion of status quo revenues.

Recall that these welfare measures not only compensate fishermen for having to reallocate their effort into less profitable areas, but it also accounts for fleet congestion and variability of profits associated with areas. Consequently, as areas are closed and fishermen reallocate their activity, such that a higher concentration of effort (*e.g.*, Option 8 in Maine), fishermen have higher economic welfare loss. Similarly, EFH closures might also force fishermen to select areas where the resource abundance is uncertain or landings per trip tend to be highly variable, and the

[8] Maps of predicted activity post-closure are available from the authors.

Table 4
Yearly Economic Impact from EFH options: No Trip Changes and No Change in Quotas

Fishery	EFH Option	Per-trip Compensation (*C*)	Trips	Total Compensation
Surfclam	Status Quo	0	2,114	0
	Option 2	0	2,114	0
	Option 3	$2	2,114	$4,228
	Option 6	$71	2,114	$150,094
	Option 8	0	2,114	0
Quahog	Status Quo	0	2,137	0
	Option 2	0	2,137	0
	Option 3	$1,065	2,137	$2,275,905
	Option 6	$2,637	2,137	$5,635,269
	Option 8	0	2,137	0
ME Quahog	Status Quo	0	1,898	0
	Option 2	0	1,898	0
	Option 3	Complete Closure	0	Complete Closure
	Option 6	0	1,898	0
	Option 8	$888	1,898	$1,685,424

welfare measure will compensate them for a greater impact since it takes into account all of the factors underlying the estimated decision rule.

Our proxy for congestion is undoubtedly entangled with information effects. If better data were available to disentangle congestion and information, it is likely that congestion effects would have been more pronounced in model estimates and policy simulation scenarios.

Conclusions

In this paper, we have demonstrated how to move from conceptual models of site choice to models of fishing behavior. These behavioral models may then be used to measure changes in welfare and predicted shares resulting from EFH designations. Our analysis demonstrates that short-run impacts on fishermen can be quite large. Longer-term impacts might be dampened if the fleet moves to different ports or fisheries in an effort to lessen the impacts of the restrictive area closures. Also, there may be substantial long-term benefits generated from EFH regulations. Because of inadequate information, however, we were unable to consider those potential long-term benefits. For two policies considered in this paper, some portion of the fleet was essentially shut down; that is, their spatial choice set was closed completely. The models presented here do not capture the welfare losses to these firms, since the model makes no allowance for port changes or other longer-term changes that might mitigate the effect of the closures.

The model we present offers a method of incorporating the effects of other fisher's choices into an individual's choice model. Our model allows vessel operators to re-optimize their current choice when faced with closures by making a guess as to what the rest of the fleet may do and then choose their best area accordingly. Using such a model introduces some complications for welfare analysis and estimating post-policy spatial choice shares. We present a method for incorporating these spillover effects into policy and welfare analysis. While crowding did not prove to be a major driver of area choice in this case, there may be other fisheries for which this could be a significant problem. For these fisheries, crowding must be included in the analysis of EFH closures.

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