The Benefits of Rationalization: The Case of the American Lobster Fishery

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The Benefits of Rationalization: The Case of the American Lobster Fishery

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Abstract *The American lobster (*Homarus americanus*) fishery is currently the most valuable fishery on the Atlantic coasts of both the USA and Canada based on ex-vessel value. Lobster conservation policies have traditionally focused on technical restrictions such as minimum size requirements, v-notching, and a prohibition on taking egg-bearing females to protect the resource, rather than direct controls on fishing effort or catch. However, in 2005 the Atlantic States Marine Fisheries Commission adopted a plan for the southern New England lobster management area (Area 2) that establishes a structure for limiting the number of license holders and the number of traps each lobsterman can have in the water. In this article, a bio-economic modeling exercise is employed to examine the biological and economic impacts of reductions to the level of fishing effort in a fishery that is modeled to represent the full-time lobster fishing fleet in Area 2. Model results show that a reduction in fishing effort has the potential to: (i) improve the sustainability characteristics of the lobster resource and, in contrast to popular belief, (ii) actually stimulate economic growth in the coastal economy.*

Key words Bio-economic simulation model, economic efficiency, lobster, rationalization, regional input-output model.

JEL Classification Codes C15, C67, Q22.

Introduction

The American lobster (*Homarus americanus*) fishery is currently the most valuable fishery on the Atlantic coasts of both the USA and Canada in terms of ex-vessel value. Historically, lobster conservation policies have focused on technical measures such as those affecting the size or condition of lobsters taken in the fishery rather than direct controls on fishing effort or catch. Area management and uniform trap limits across areas were adopted along the Atlantic coast of the USA in the late

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1990s, but effective control of fishing effort remains elusive because of the open-access nature of the fishery and continued reliance on technical measures.

Today, there are seven Lobster Conservation Management Teams (LCMTs) along the Atlantic coast of the USA that guide development of conservation plans within each Lobster Conservation Management Area (LCMA). This paper focuses on LCMA 2 (southern New England inshore waters; see figure 1). Initially, management measures developed by the Area 2 LCMT were limited to a cap on the number of traps (800) that could be fished by Area 2 license holders, a trap tag system, and a recommended control date to forewarn participants that future participation in Area 2 may be limited. To meet rebuilding requirements, in 2001 the Area 2 LCMT recommended a schedule of gauge size increases that would eventually change the minimum size from 3-1/4" to 3-3/8" over four years. However, larger than anticipated stock declines and increased incidence of shell disease, coupled with increasing concern over the risk of entanglement of endangered whales and other marine life in lobster trap buoy lines, have precipitated unprecedented regulatory attempts to control fishing effort in LCMA 2. In 2005, the Atlantic States Marine Fisheries Commission (ASMFC) adopted a plan for Lobster Management Area 2 that establishes a structure for limiting the number of license holders who are eligible to fish in Area 2 and an individualized trap limit for each lobsterman (ASMFC 2005). The challenge at this point is to obtain an understanding of both the biological and economic impacts of potential adjustments in the level of fishing effort in Area 2.

There is a large body of theoretical literature that predicts improvements in fishery resources and in the economic benefits derived from those resources as a result of limiting fishing effort (Gordon 1954; Scott 1955; Stratton 1969; Acheson 1975; Christy 1978; Libecap 1989; Christy 1996; Grafton, Squires, and Kirkley 1996; Pauly *et al.* 2002; and Johnsen 2005). Indeed, many fisheries around the world are now managed, at least in part, through limited access programs and other forms of effort reduction in an attempt to reap the biological and economic efficiency gains publicized in the literature. However, fishery managers are concerned that although effort reduction policies may improve fishery resources and economic efficiency, the same policies could be harmful to the fishery labor community and to other businesses in the regional economy. In spite of these concerns, only a handful of fisheries studies have attempted to quantify the linkage between potential biological and economic efficiency improvements associated with effort reduction and the perceived distributional losses in regional income and employment in the economy both within and outside fishery sectors (Heen and Flaaten 2007, Bhat and Bhatta 2006, Leung and Pooley 2002). This paper explores this linkage for a fishery modeled after the full-time portion of the Area 2 lobster fleet by combining a dynamic bio-economic simulation model with a regional input-output model. The bio-economic model simulates the population dynamics of the lobster resource and the associated economic performance of the fleet over time, allowing short-term and long-term (steady-state) predictions of biomass, egg production, landings, ex-vessel price, costs, revenues, and profits associated with varying levels of effort reduction. The resulting long-run predictions of aggregate fleet costs and profits are then fed into a regional input-output model to measure how the fleet-wide efficiency gains (reduced fishing costs, increased profits) realized from effort reduction impact other businesses in the regional economy.

The modeling exercise demonstrates that effort reductions could increase the size distribution of lobsters in the lobster population and increase biomass and egg production relative to the same resource with higher fishing intensity. Recognizing that environmental conditions play a significant role in the relative productivity of

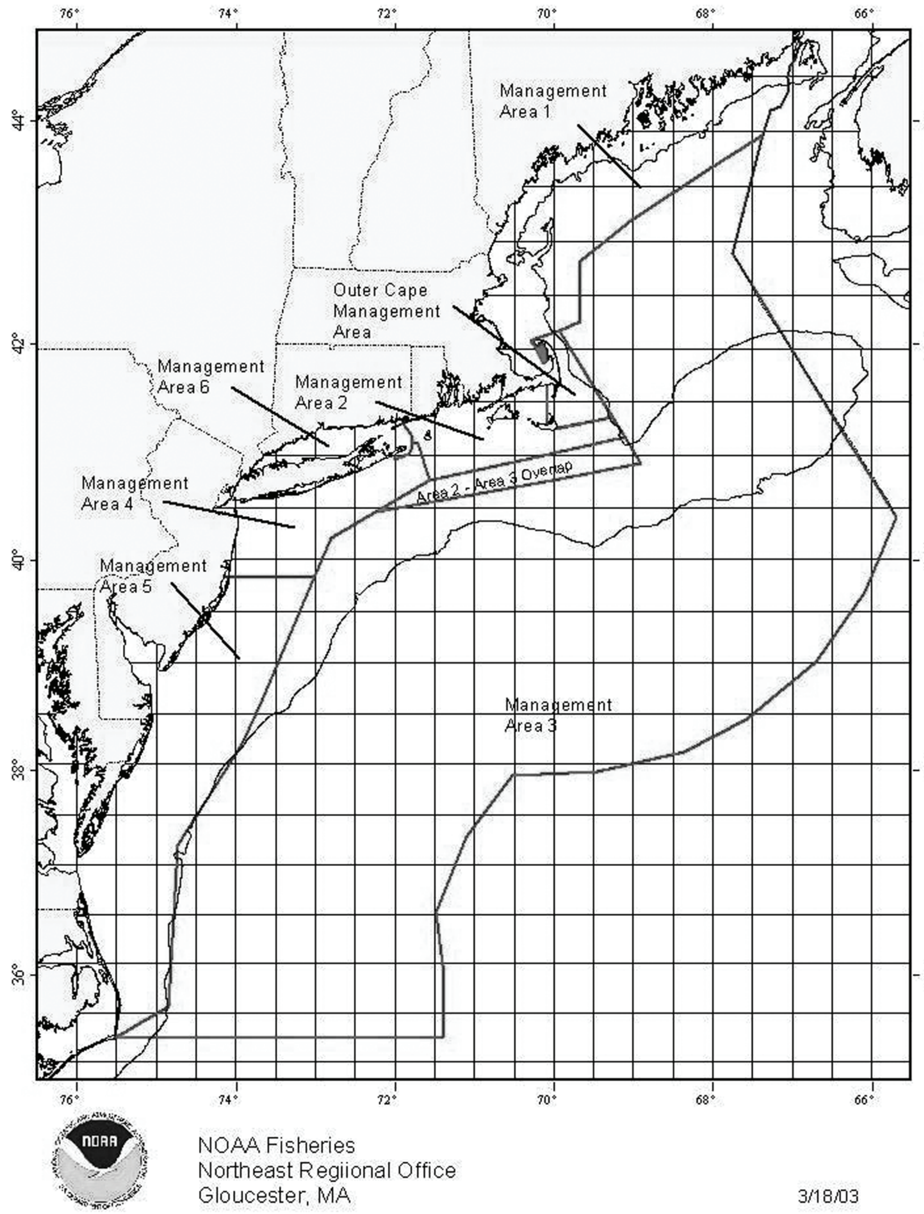

Figure 1. Map of Lobster Management Areas
Note: Established by the Atlantic States Marine Fisheries Commission through Amendment #3 to the Interstate Management Plan for American Lobster.

the resource at different times, the biological results from the modeling exercise imply that lower fishing intensity should produce higher landings with a greater margin of safety at any resource productivity level.

The economic results demonstrate that the gains in harvesting efficiency from implementation of an effective effort control program could create higher incomes for participating vessel owners and crew, and stimulate additional economic growth in sales and income for other businesses in the regional economy. Most importantly, the economic analysis sheds light on the issue of "efficiency versus jobs." The results of this study generally indicate that while fewer fishing jobs will result from gains in harvesting efficiency, these losses may be largely offset by gains in employment in other sectors of the regional economy.

The rest of this paper is structured as follows. The next section presents the four effort reduction management scenarios analyzed in this study. We then introduce the two models employed for this study: (*i*) a bio-economic simulation model (SIMLOB) that incorporates the fundamental linkages between the population dynamics of the lobster resource and the harvest sector in Area 2; and (*ii*) a regional input-output model that examines how the fleet-wide economic results from SIMLOB will impact the sales, income, and employment of other businesses in the regional economy. Results of the SIMLOB runs and the input-output assessment are shown next, and then we summarize the overall findings and provide some concluding remarks.

Policy Management Scenarios

To examine the impact that an effort control program could have on the Area 2 lobster resource, fishermen's income, and the regional economy, the biological and economic effects of four effort reduction scenarios were analyzed under baseline conditions that prevailed in Area 2 in 2003. In an attempt to mimic the resource and market conditions that existed in 2003, the SIMLOB model was calibrated to generate the fleet characteristics, landings, and value estimates reported by the full-time Area 2 lobster fleet in 2003. The calibration also matched the size distribution of the modeled catch to the size distribution indicated by sea sampling records available from the Rhode Island Division of Fish & Wildlife. Calibration to observed 2003 fishery conditions provides a degree of integrity to the model and makes it possible to compare the long-term sensitivity of output variables to incremental changes in policy-relevant variables.

By 2003, the Area 2 lobster fleet had experienced considerable attrition, as reflected in the decline in the number of license holders reporting at least one pound of lobsters in 2003 (415) compared to only five years prior (583 in 1999). Lobster fishing activity varies considerably among these license holders, however, as measured by landings. Available data used to determine eligibility for limited access and assign initial trap allocations indicate that annual landings among license holders during 2001 through 2003 ranged from upwards of 50,000 pounds to less than 10 pounds of lobster (McKiernan 2006). In 2001 and 2002, about 95 license holders (about 20% of the Area 2 fleet) landed about 70% of total Area 2 landings. During 2003 the number of license holders, accounting for at least 70% of total landings, had fallen to 80. This means that the majority of the 2003 fishery could be approximated using a full-time fleet of 80 lobster boats. Further, cost data used to construct production functions for the input-output model were available only for a sample of full-time operators. Since the cost structure of the part-time fleet is likely to be highly variable, the absence of any cost data meant that the part-time fleet could not be incorporated into the simulation. Therefore, part-time fleet landings were held constant. The implications of this simplifying assumption are discussed later. Full-time Area 2 boats reported fishing an average of 743 traps each and hauling 267 traps per fishing day. The total estimated number of days fished averaged approximately 122 in 2003, and the minimum legal size in Area 2 in 2003 was 86 millimeters. These baseline conditions comprise the status quo fleet characteristics and minimum size requirements modeled in the first scenario (table 1).

Scenario 2 models the same baseline fleet size (80 boats), fishing days (122), and minimum size (86 mm), but the number of traps fished per boat was reduced iteratively in the model until the simulated total personal income earned by the fleet reached a long-run equilibrium maximum.[1] All of the alternative management scenarios assessed were analyzed in a similar manner, by reducing overall effort through adjustments in the number of traps fished and/or fleet size until the personal income obtained from the fishery over the long-term reached a simulated equilibrium maximum.

Scenario 3 maintains an individual scale of operation comparable to the status quo in terms of traps fished per boat (743), number of days fished (122), and minimum size requirement (86 millimeters), but examines incremental reductions in the size of the full-time lobster fleet.

Finally, Scenario 4 models simultaneous adjustments to the number of boats and traps holding the baseline number of days fished (122) and minimum size requirement (86 millimeters) constant.

Methods

The potential biological and economic implications of reductions in the level of fishing effort in Area 2 were simulated with SIMLOB, a lobster fishery bio-economic simulation model developed by Gates and Sutinen (1995). Default parameter values in SIMLOB were derived from fisheries data submitted to the National Marine Fisheries Service (NMFS) by licensed lobstermen in the early 1990s, estimates contained in Fogarty and Idoine (1988), focus group meetings with state Lobstermen's Associations in Massachusetts and Rhode Island during 1993, and management regulations that were in place in the early 1990s. For this study, that

Table 1
Summary of Input Management Scenario Parameters[a]

Scenario	Scenario Description	Fleet Size (Boats)	Traps/ Boat	Fishing Days/Year	Min. Size (mm)
1	2003 baseline conditions	80	743	122	86
2	Adjust traps	80		122	86
3	Adjust boats		743	122	86
4	Adjust traps and boats			122	86

[a] The missing fleet size and traps per boat quantities were determined exogenously by the SIMLOB model.

[1] The criteria of maximum total personal income was used to avoid the complications that would arise from consideration of different crew compensation practices and consideration of the opportunity cost of labor. Maximum personal income measures the net revenue that is left after fishing expenses other than labor.

information was reviewed and updated, if appropriate, with data obtained from NMFS, the Rhode Island Division of Fish & Wildlife, the Massachusetts Division of Marine Fisheries, and through an examination of lobster business records supplied by several full-time Area 2 lobstermen.[2]

The SIMLOB model is based on differential equations that represent dynamic processes of the lobster resource and ex-vessel price/demand relationships, and was initially developed to simulate the impact of changes in fleet characteristics and management strategies on the lobster resource and the economic performance of New England harvesters. However, SIMLOB allows users to modify parameter values and input data to simulate the performance characteristics of a segment of the lobster fishery; in our case the Area 2 fishery.

Resource Sector Component of SIMLOB

The biological equations contained in SIMLOB are based on the work of Fogarty and Idoine (1988) and are explained in detail in Gates and Sutinen (1995). The equations that describe the basic dynamics of the lobster fishery incorporate growth, mortality, and molting parameters specific to nine size cohorts. The nine cohorts are distinguished by their carapace lengths and sex. The lower and upper lengths for cohort i of sex k are given by $ll(i,k)$ and $ul(i,k)$, respectively, where $ll(i,k) \leq size < ul(i,k)$. The nine size cohorts correspond to market categories. These market categories include chix (approximately 1 lb.), eighths (1.125 lbs.), quarters (1.125 lbs.), halves (1.5 lbs.), three quarters (1.75 lbs.), and twos-plus (2 lbs. and above).

The weight of individual lobsters within each cohort is calculated using the carapace length-weight formulas estimated by Fogarty and Idoine (1988) and is based on the average carapace length of the cohort. Average carapace length is calculated as: $acl(i,k) = [ul(i,k) + ll(i,k)]/2$, where i is the ith cohort group, k is the sex, acl is the average carapace length of the cohort, ul is the upper limit of the cohort's carapace length, and ll is the lower limit of the cohort's carapace length. The average carapace length is then used to calculate an individual lobster's weight according to the equation $wt(i,k) = A(k) * acl(i,k)^{B(K)}$, where wt is an individual lobster's weight, the parameter A is equal to 0.000149 for males and 0.000834 for females, and the parameter B is equal to 3.347 for males and 2.972 for females.

The relationship between size-specific annual molt probability and carapace length is determined from the logistic equation estimated by Fogarty and Idoine (1988):

$$m\_prob(i,k) = 1 \Big/ \left\{1 + \exp\left[A1(k) + B1(k) * cl(i,k)\right]\right\},$$

where m_prob is the probability of molting in a year, the parameter $A1$ is equal to –6.886 for males and –6.867 for females, and the parameter $B1$ is equal to 0.052 for males and 0.058 for females.

The stock-recruitment relationship for the Area 2 fishery is unknown, so constant annual recruitment of 3.4 million lobsters for each sex is assumed, regardless

[2] The cooperating lobstermen provided estimates of operating costs and earnings for a typical Area 2 lobster operation. The estimates were based on business records of the cooperating lobstermen and an understanding of how their performance compared to the rest of the fleet. In addition to being active participants in the fishery, the cooperating lobstermen are considered to be very knowledgeable of the Area 2 industry as a whole. The participants consisted of a former president of the Rhode Island Lobstermen's Association, a former Chairman of the Area 2 Lobster Management Team, and a prominent lobsterman that has held various positions with lobstermen's associations in the past.

of the size of the parent stock. This recruitment value was calculated through calibration of the model and measures the number of recruits that were necessary to produce the observed 2003 catch of the identified Area 2 full-time fleet. If there is, in fact, a positive relationship between stock size and recruitment, model results will underestimate the benefits of conservation measures that increase the parent stock. The same logistic function that distributes the annual molting probability throughout the molting season is used to distribute annual recruitment throughout the recruitment season, since the timing of recruitment is assumed to be identical to the timing of the molting process.

Annual growth among size cohorts is determined by combining molt increment and molt probability estimates. The distribution of lobsters among larger size cohorts is controlled by a set of size and sex specific transition probabilities, $prec(i,k)$, which is the probability that a lobster of sex k will enter size class i. The transition probabilities are generated using numerical integration of a gamma density function, calculated to be consistent with the mean growth regressions of Fogarty and Idoine (1988). The gamma density function is dependent upon the mean molt increment and the variance. The mean molt increment is calculated from the equation estimated by Fogarty and Idoine (1988): $(i,k) = A2[k] + B2[k] * acl[i,k]$, where $I(i,k)$ is the mean molt increment, $acl[i,k]$ is the premolt carapace length, the parameter $A2[k]$ is equal to 8.963 for females and 16.229 for males, and the parameter $B2[k]$ is equal to –0.03 for females and 0.083 for males. The variance is obtained by assuming a coefficient of variation equal to 1.5.

Natural mortality in the model is represented by the parameter $nm(j,i,k)$. The default natural mortality rate in SIMLOB is an instantaneous rate of 0.014 per month, which corresponds to an annual rate of 0.16. This rate is the same for both sexes and for molting and non-molting lobsters and approximates the fishery-wide natural mortality rate that has been used in lobster stock assessments during the 1990s (ASMFC 2006). However, The Rhode Island Division of Fish & Wildlife estimates a three-fold increase in this natural mortality rate in recent years for the Rhode Island lobster resource (Gibson 2006). The most recent stock assessment for American lobster also presents growing evidence that natural mortality rates experienced by the southern New England stock of lobsters may have increased substantially in recent years (ASMFC 2006). Therefore, for the purposes of this study, the default natural mortality rates in SIMLOB were tripled to simulate current conditions in Area 2.

Fishing mortality produced in the model varies by cohort, sex, and month of the year and is represented by the parameter $fm(j,i,k)$. The fishing mortality parameter is explained in the next section.

The proportion of a cohort that survives natural and fishing mortality is determined by $survive\_propor(j,i,k) = exp(-Z)$, where Z is total mortality and is equal to $nm(j,i,k) + fm(j,i,k)$. Additionally, within a cohort the proportions of lobsters that do and do not survive a molt into a higher cohort are given by $survive\_molt(j,i,k) = survive\_proper(j,i,k) * molt\_prob(j,i,k)$ and $survive\_not\_molt(j,i,k) = survive\_proper(j,i,k) * (1 - molt\_prob(j,i,k))$.

The predicted number of lobsters in each cohort i, sex k, and month j, is determined by $c\_pop(j,i,k)$. A cohort's population in any month, j, consists of two parts: lobsters that survive the previous month and do not molt out of the cohort and lobsters that molt into the next cohort. This is defined as $c\_pop(j,i,k) = c\_pop(j-1,i,k) * survive\_not\_molt(j-1,i,k) + \sum_{i=0}^{i-1}\{c\_pop(j-1,i,k) * survive\_molt(j-1,i,k)\}$. The total number of lobsters in the population in month j is calculated by $population(j) = \Sigma_i \Sigma_k c\_pop(j,i,k)$. The total biomass of a cohort is given by $cohort\_biomass(j,i,k) * wt(i,k)$. Therefore, the biomass of the total population and the biomass of the exploitable population are calculated by:

$$total\_biomass(j) = \sum_i \sum_k cohort\_biomass(j, i, k)$$

and

$$exploit\_biomass(j) = \sum_i \sum_k cohort\_biomass(j, i, k) * xlegal(i, k),$$

where *xlegal*(*i,k*) is the proportion of lobsters in cohort *i* and of sex *k* between the minimum and maximum legal sizes. In combination, the population, exploitable population, biomass, and biomass of the exploitable population provide a comprehensive picture of the status of the lobster stock at each point in time.

Harvest Sector Component of SIMLOB

Within the harvest sector of the SIMLOB model, the amount caught and kept by each lobster producer is determined from the values assigned to several variables by the user (Gates and Sutinen 1995). These variables are: (*i*) number of traps hauled per day (*hauls*(*j*)); (*ii*) number of traps in the water (*traps*(*j*)); (*iii*) number of days fishing during a month (*days*(*j*)) (taken together, these three variables determine the average soak time per trap (*soaktime*(*j*)); and (*iv*) crew size (*crew*(*j*)). The values of these variables determine each producer's catch, total catch, and actual ex-vessel price for the month (Gates and Sutinen 1995). In the model, it is assumed that at the beginning of each month each producer knows the size and composition of the lobster population for the month, is aware of the current fleet size, and has formulated an expected ex-vessel price. Following the description contained in Gates and Sutinen (1995), the rest of this section shows how the levels of fishing mortality, catch, profits, fleet size, and price are determined.

The level of each producer's fishing mortality is calculated by *days*(*j*) * *hauls*(*j*) * *f*(*soaktime*(*j*),*i,k*), where *days* is the number of days at sea during the month, and *hauls* is the number of trap hauls per day at sea. The function *f*() is the catchability per trap hauled and depends on the amount of time the trap is in the water between hauls (*soaktime*) and the weight of the cohort harvested (*cohort_biomass*). Various models have been suggested to describe the relationship between catch and soak time. SIMLOB uses a soak time model that includes an asymptotic saturation value that is characteristic of passive fishing gear (Kennedy 1951; Gulland 1955; Beverton and Holt 1957; Sinoda and Kobayasi 1969). The functional form of *f*() is defined as *f*(*soaktime*(*j*),*i,k*) = *A*[*i,k*] * [1–exp{–*B*[*i,k*] * *soaktime*(*j*)}], where the parameter (*A*[*i,k*]) varies by month and is determined during calibration of the model by adjusting the coefficient to produce monthly catch per trap haul values that match the performance of the fishery with the indicated number of boats, traps, traps hauled per day, and days fished. The parameter *B*[*i,k*] is the saturation value that describes the relationship between catch and changes in soak time. This parameter value was set equal to 0.36 using the function form defined in Sinoda and Kobayasi (1969).

The catchability function *f*() deserves special attention because it is not known how the value of the function will change as lobster population sizes and trap numbers change from those with which we have recent experience. For this exercise, an assumption was made that a smaller number of traps would reduce the catchability of traps compared to a larger total number of traps. This assumption is based on the idea that the density of traps has an effect on the ability of lobsters to find the traps. Preliminary model runs indicated that catches would remain higher than seemed reasonable at low trap numbers unless the catchability per trap was reduced. The method used to reduce the catchability was to reduce it in proportion to the density of traps in Area 2, using an approximate area of lobster fishing ground in Area 2 of 1,100 square miles. If catchability does not decline in proportion to trap density, the model results would tend to overstate the number of traps that are needed to make the indicated catches.

Similar uncertainty led to an artificial constraint on the average pounds per trap that a trap could catch. Large reductions in modeled trap numbers resulted in increasing the size of lobsters and the catch rate of the remaining traps to a level beyond that ever observed in Area 2. Whereas traps have a physical limit on their capacity, a constraint of 15 pounds per trap haul was established as a limit to modeled changes. Without that constraint, modeled trap numbers could have been further adjusted, but the practicality of the results would have been suspect.

A fishing mortality value for each cohort and sex in every month is also required for both the resource and harvest sector components of SIMLOB to update the size and composition of the stock each month. These fishing mortality values are calculated by: $fm(j,i,k) = fleet\_l(i) * days(j) * hauls(j) * f(soaktime(j),i,k)$, where $fleet\_l(i)$ is the number of lobster producers operating during month i.

In SIMLOB, fishing mortality affects only legal-sized lobsters. That is, harvesters are assumed to comply with carapace length restrictions, and all nonconforming lobsters are released alive. Individual lobsters are assumed to be eligible for removal in proportion to the numbers in the cohort that are of legal size. The portion of a cohort's size range that lies outside the legal range is ineligible for removal. To calculate this, the cohort's upper and lower carapace lengths are compared to the minimum and maximum legal size limits. The portion of a cohort eligible to be removed by fishing is given by:

$$
\begin{aligned}
xlegal(i,k) &= (ul(i,k) - min\_size\_limit)/(ul(i,k) - ll(i,k)) \text{ if } ul(i,k) \\
&\quad > min\_size\_limit \;\&\; ll(i,k) < min\_size\_limit \\
&= (ll(i,k) - max\_size\_limit)/(ul(i,k) - ll(i,k)) \text{ if } ul(i,k) \\
&\quad > max\_size\_limit \;\&\; ll(i,k) < max\_size\_limit \\
&= 1.0 \quad \text{if } ul(i,k) < max\_size\_limit \;\&\; ll(i,k) > min\_size\_limit \\
&= 0.0 \quad \text{if } ul(i,k) < min\_size\_limit \text{ OR } \mathrm{ll}l(i,k) > max\_size\_limit,
\end{aligned}
$$

where $xlegal(i,k)$ is the proportion of a cohort i and sex k eligible to be removed by fishing, min_size_limit is the legal carapace length, and max_size_limit is the maximum carapace length.

The weight of total fleet landings in a month is calculated by:

$$total\_catch(j) = \sum_i \sum_k [1 - \exp\{-fm(j,i,k)\}] * c\_pop(j,i,k) * wt(i,k) * xlegal(i,k).$$

An individual producer's landings for a month are assumed to be an equal share of total monthly catch according to $catch(j) = total\_catch(j)/fleet\_l(i)$.

Expected total revenue for a month is given by $TR(j) = E\{price(y,j)\} * catch(j)$. Producers are assumed to formulate an expected price for each month based on past prices. The actual price in a given year and month is defined by $price(y,j)$. The expected price in a given year and month is given by $E\{price(y,j)\}$, where E is the expectation operator, y is the year index, and j is the month index. The expected price is updated as:

$$E\left\{price(y, j)\right\} = \alpha E\left\{price(y-1, j)\right\} + (1-\alpha) * \left[price(y, j-1) - E\left\{price(y, j-1)\right\}\right],$$

and the expected price for the same month next year is updated as:

$$E\left\{price(y+1, j)\right\} = \beta E\left\{price(y, j)\right\} + (1-\beta) * \left[price(y, j-1) - E\left\{price(y, j-1)\right\}\right],$$

The coefficients α and β are positive and less than one, but the absolute values of these coefficients are unknown and are assumed to be 0.25 and 0.50, respectively.

Total monthly costs, excluding labor, are determined by: $TC(j) = C_0 * days(j) * hauls(j) + C_1 * days(j) + C_2 * traps(j) + FC(j)$, where C_0 represents bait costs, C_1 represents variable costs such as fuel and supplies, C_2 represents the rental costs of traps, and FC represents fixed costs such as insurance and dockage fees (see table 2 for a complete list of cost categories included in the model). Labor cost is given by $CS(crew) * TR(j)$, where $CS(crew)$ is the crew's share of total revenue. $CS(crew)$ is equal to 0, 0.16, or 0.32 when *crew* equals 0, 1, or 2, respectively. As such, a producer's expected profits for a month are given by: $\pi(j)[1 - CS(crew)] * TR(j) - TC(j)$.

Maximization of profits, $\pi(j)$, with respect to the variables that were examined in this research (*soaktime, hauls, traps, days, crew*), is accomplished through iterative adjustments until the values yield maximum expected profits, given stock size and composition and expected price.

The SIMLOB model provides two options for generating predicted ex-vessel prices. One option uses coefficients from an inverse demand equation based on the work of Cheng and Townsend (1993). This option allows incorporation of endogenously determined monthly prices and may be used when evaluating impacts of management policy on the New England fishery as a whole. The second option, based on Waugh and Miller (1970), captures monthly patterns in ex-vessel price independent of changes in quantities supplied. This formulation is appropriate when

Table 2
Primary Expense Categories for the Area 2 Lobster Fleet

Primary Expense Categories (Excluding Labor)
Fuel & lubricants
Repair & maintenance: vessel
Bait
Gear replacement
Licenses and permits
Moorage, dockage, haulout
Boat insurance
Interest payment: vessel
Professional fees
Administrative expenses
Repair & maintenance: electronics
Vehicle
Dues and subscriptions
Rent
Taxes
Boat principal payment
Miscellaneous supplies

modeling a segment of the lobster fishery that is too small to affect lobster markets. Effectively this means the lobster producers in Area 2 are assumed to be price takers in lobster markets. Due to the dominance of lobster landings from the Gulf of Maine stock area, Maine in particular, the Waugh and Miller option was used for this study.[3]

The Waugh and Miller formulation involves estimating the parameters of a sine-cosine function measuring the peaks and valleys of a seasonal distribution of prices. Given the assumed inability to affect lobster prices, an alternative would be to hold prices constant at their monthly average. However, the Waugh and Miller specification provides greater flexibility to incorporate potential changes that might influence either the timing or amplitude of seasonal high and low prices. Predicted prices are calculated as:

$$price(j) = e^{intercept*w(j)^{\gamma} + \alpha*\sin(\psi+\omega*t)+\beta*\cos(\psi+\omega*t)},$$

where j denotes size class, intercept is average annual price, w is average weight, t is month, γ measures price responsiveness to change in lobster size, ψ is a phase parameter affecting the positioning of the seasonal peak price, γ is the amplitude parameter for the sine function, β is the amplitude parameter for the cosine function, and ω is set equal to $\pi/6$, representing an annual cycle. The default parameter values for γ, ψ, α, β, and ω provided in the SIMLOB model were used and held constant for all scenarios (table 3).

If the average weight of lobsters in each size class (< 1-3/4 pounds and ≥ 1-3/4 pounds) does not change, then the resulting predicted monthly price would be equivalent to using a constant monthly average price. However, the policy simulations considered herein provide some rebuilding of the lobster resource affecting the size distribution of marketed lobsters from Area 2. This means that predicted monthly average prices change over time, which may result in some upward bias in the predicted prices, hence, total Area 2 revenues. This effect is embedded in the fact that *ceteris paribus*, the predicted price is a continuous function which depends on the average weight of lobsters, while lobsters are typically priced as a step function. For example, the price per pound would be the same for any lobster from 1-1/4 to less then 1-1/2 pounds. That is, a 1-1/4 and a 1-3/8 pound lobster would be the same price per pound, yet the predicted price in SIMLOB would be slightly lower for the former. This tendency to overstate prices and thus total revenue is not likely to be particularly large for lobsters below 1-3/4 pounds, since even under improved

Table 3
SIMLOB Default Parameters for Waugh and Miller Predicted Prices

Parameter	Default Value
Intercept	1.370443
α	0.217145
β	–0.0723
ψ	0.224549
ω	0.523599
γ	0.155094

[3] In 2003 landings of lobster from the entire Southern New England stock area were less than 8% of total domestic landings. Since Area 2 is included in the Southern New England stock area, total 2003 landings from Area 2 alone would be less than 8%.

resource conditions, the proportion of lobsters less than 1-3/4 pounds would still be quite large, so the average weight would not be appreciably affected. The potential upward bias is likely to be larger at higher resource levels since the average weight of lobsters in the upper size class (more than 1-3/4 pounds) would increase. The actual magnitude of this effect would be modified somewhat by the fact that the proportion of marketed lobster in this size class would still be small compared to that of the smaller size class (less than 1-3/4 pounds).

Regional Input-Output Assessment

The second modeling exercise carried out for this study was a regional input-output assessment that examined how the fleet-wide economic results from SIMLOB will impact the sales, income, and employment of other businesses in the regional economy. The economic contribution or impact of Area 2 lobster harvesting to the overall regional economy extends well beyond simply measuring the income, employment, and ex-vessel revenues of harvesting activities. In addition to these direct contributions, indirect contributions to the regional economy are generated through intersectoral linkages to non-fisheries sectors. For example, lobstermen purchase goods and services to maintain and operate their vessels. Businesses providing these goods and services must also purchase inputs from their suppliers in order to conduct these transactions. In turn, these suppliers then purchase goods and services from their own suppliers, triggering a whole series of additional indirect multiplier effects. This cascading series of industry-to-industry, backward-linked multiplier effects and the cycle of consumption spending induced by all the incomes generated in these economic activities, contributes to the economy's employment and income base and continues until all of the multiplier effects are derived from outside the local economy. The summation of the direct, indirect, and induced multiplier effects that remain within the local economy represent the total economic contributions or impacts of a particular industry sector to the overall regional economy.

Although input-output analysis is the most common approach for describing the structure and interactions of regional economies, several assumptions regarding linear production functions, constant relative prices, and zero-substitution elasticities in consumption and production are of questionable validity. Nevertheless, Propst and Gavrilis (1987) considered these assumptions when comparing economic impact procedures and concluded that the input-output modeling approach can satisfy the widest range of information needs at high precision levels if primary data are utilized for the main sectors of interest as was done for this study (*i.e.*, lobster operating expenditure data). For a comprehensive description of the input-output modeling technique see Miller and Blair (1985).

In the assessment provided here, a ready-made regional input-output system called IMPLAN Pro (Minnesota IMPLAN Group, Inc.) was employed to predict the contribution of the Area 2 lobster harvesting industry, under the four different management scenarios, to the overall regional economy of Rhode Island and three coastal counties in Massachusetts (Bristol, Barnstable, and Dukes).[4] The total estimated sales, personal income, and employment contributions attributable to Area 2

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[4] This regional designation was chosen mainly because vessels that fish in Area 2 operate out of ports located in this area. However, it was also necessary to construct the impact region geographically based on counties since the transactions-level data contained in the input-output model are only available at the county level. Whereas all of the counties in Rhode Island are coastal counties that contain Area 2 lobster harvesting businesses, only Bristol, Barnstable, and Dukes County in Massachusetts were assumed to contain businesses that land lobsters in Area 2.

lobster harvesting in this region are differentiated by: (*i*) the direct contributions attributed to the lobster fleet, (*ii*) the values attributed to the fleet's operating expenditures, and (*iii*) the values originating from income expenditures by vessel owners, captains, and crew. It is desirable to show separation of the impacts in this manner under each management scenario in order to highlight the differing results across management scenarios.

Fleet Operating Expenditures

The region-wide multiplier effects attributed to the operating expenditures of the Area 2 lobster fleet are estimated by multiplying the total value of each of the individual expense items (see table 4 for list of items) that is spent within the region by the corresponding IMPLAN-generated multiplier. The IMPLAN Pro multipliers measure the total sales, income, and employment change in each economic sector within the region caused by a $1 change in output in any particular sector. Therefore, the product of the expenditure values that are spent within the region with their matching IMPLAN-generated multiplier provides an estimate of the contribution of each particular expenditure item to the regional economy.

Data limitations, however, precluded our ability to differentiate between items purchased from local businesses and those purchased from businesses located outside the region. Goods and services purchased from businesses located outside of the study region impact the economies of other regions and should be excluded from the assessment. Fortunately, through the use of regional purchase coefficients (RPCs), the IMPLAN Pro system has the ability to remove the value of imports from the regional economic accounts prior to generating impacts. An RPC for a particular industry sector's output indicates the portion of the total regional demand supplied by the local producers. The IMPLAN-generated RPCs are estimated with a set of econometric equations, and there is one value for each commodity produced by a given sector.[5] By incorporating IMPLAN Pro's RPCs for all commodity-based transactions, we were able to estimate the amount of each purchase that was supplied by local businesses.[6] These adjusted expense values were then applied to the IMPLAN-generated multipliers to estimate the regional contribution of each item.[7]

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[5] This implies that all industries are assumed to purchase a particular good or service from local sources at the same rate. Because of the many difficulties involved in characterizing regional commodity demand on an industry-by-industry basis, ready-made input-output models, such as IMPLAN Pro, typically provide only these uniform average values. Through primary data collection, however, it may be possible to obtain a full matrix of RPCs.

[6] The estimated low default RPC values associated with the supply of bait (*i.e.*, herring and skates) from local fishermen and wholesalers, however, did not reflect the actual trade flows of the region. Area 2 lobstermen purchase virtually all of their bait from local harvesters and dealers, so the RPC for the commercial fishing and wholesale trade sectors were set equal to one.

[7] Three of the expenditure categories were adjusted further prior to generating impacts. In an input-output model, a large portion of property insurance and interest payments generate no economic impact. The output of most industries in an input-output model is expressed in terms of business receipts, but the insurance carrier and the banking sectors are measured on a net basis. The output of the insurance carrier sector is calculated by subtracting claims and policy dividends paid from premiums earned. The output of the banking sector is more complicated and generally includes interest payments on loans and many other income-generating activities, but also accounts for the interest paid by banks on depositors' funds and for bank services where no explicit charges are made. As such, if the total estimated value of the property insurance and interest payments made by vessel owners were applied to the input-output model's multipliers, the impact on the local economy would be overstated. To provide net expenditure estimates that would equate to the values contained within IMPLAN Pro, the expenditure estimates were adjusted by the average net profit margin percentage for property and casualty insurance firms in the Northeast (10%) and the average net profit margin percentage for the banking industry in the Northeast (22%; http://biz.yahoo.com/p/).

Table 4
Bridge Between Primary Expense Categories and Associated IMPLAN Pro Sectors

Primary Expense Categories	Allocation Percentages and IMPLAN Pro Sector Descriptions[a]
Fuel & lubricants	80% Petroleum refineries, 20% petroleum lubricating oils
Repair & maintenance: vessel	100% Ship building and repairing
Bait	50% Commercial fishing, 50% wholesale trade
Gear replacement	80% Spring and wire product manufacturing, 20% other miscellaneous textile product mills
Licenses and permits	100% State and local non-education
Moorage, dockage, haulout	100% Recreation industries, other amusement, gambling (includes marinas)
Boat Insurance	100% Insurance carriers
Interest payment: vessel	100% Monetary authorities and depository credit intermediation
Professional fees	100% Accounting and bookkeeping services
Administrative expenses	100% Stationery and related product manufacturing
Repair & maintenance: electronics	100% Electronic equipment repair and maintenance
Vehicle	20% Automotive repair and maintenance, 80% petroleum refineries
Dues and subscriptions	100% Civic, social, professional, and similar organizations
Rent	100% Real estate
Taxes	80% Federal non-military, 20% state and local non-education
Boat principal payment	100% Ship building and repairing
Miscellaneous supplies	1.46% Curtain and linen mills; 1.31% other miscellaneous textiles 6.82% paper and paperboard mills; 30.81% paperboard container manufacturing; 4.05% coated and uncoated paper bag manufacturing; 8.05% soap and other detergent manufacturing; 6.84% polish and other sanitation good manufacturing; 9.26% plastics packaging materials; 1.42% plastics plumbing fixtures and all other plastics; 1.13% tire manufacturing; 1.23% AC, refrigeration; 12.78% other engine equipment manufacturing; 0.78% air and gas compressor manufacturing; 1.27% watch, clock, and other measuring devices; 2.07% electric lamps and bulbs manufacturing; 0.88% electric power and transformer manufacturing; 1.75% primary battery manufacturing; and 8.09% motor vehicle parts manufacturing

[a] Allocation proportions for individual expense items allocated to two IMPLAN Pro sectors were based on professional judgment. Expenditures on miscellaneous supplies were distributed to IMPLAN Pro sectors according to proportions contained in the default IMPLAN Pro commercial fishing sector's production function. Miscellaneous supplies were assumed to consist of expenditures for cleaning products, boxes, packaging materials, miscellaneous machine parts, plumbing supplies, electrical components, other engine equipment, refrigeration equipment, and vehicle parts.

The summation of the economic impacts across expenditure items indicates the total sales, income, and employment attributable to the lobster fleet's operating expenditures (excluding labor) in the regional economy.

Income Expenditures by Owners, Captains, and Crew

The income earned by vessel owners, captains, and crew members generates additional economic impacts through the mix of goods and services purchased from businesses located in the region. Calculation of these secondary impacts, however, requires assumptions about the goods and services that are purchased and the levels of disposable income available for spending. The IMPLAN Pro system contains a personal consumption expenditure (PCE) activity database that represents the national average expenditure pattern for disposable income according to nine different annual household income classes.[8] Each of the nine PCE vectors show the average proportion of goods and services that will be purchased from a given IMPLAN Pro sector for each dollar of spending. Spending patterns differ dramatically between income levels. Low-income spending is more heavily weighted toward necessities (*i.e.*, food, clothing, shelter), while higher-income levels provide more money for recreation and luxury spending. In absence of a primary expenditure survey that identifies the specific spending patterns of lobster vessel owners, captains, and crew members, the nine IMPLAN Pro PCE vectors provide a reasonable approximation of the goods and services that are purchased with the income earned from lobster fishing.

The income earned by spouses also contributes to the income base of households and may raise the level of income available for spending. This additional income was estimated from U.S. Department of Labor and Census Bureau data, and was added to the money earned from lobster fishing to determine total household income levels (USDL 2005; USCB 2005).[9] Although the contribution of spousal income to total household income was generally quite low, it did have an effect on which PCE profile was chosen to represent the household spending patterns associated with changes in lobster fishing earnings.

A portion of household income is not available for spending, however. Income is subject to various taxes and many households engage in some level of savings. These activities vary by income level and must be removed since they are not captured in the PCE vectors. Data contained within IMPLAN Pro's social accounting matrix provides information about taxes and savings in the study area and can be used to derive disposable income rates for each of the nine household income categories. These rates varied from 96.6% for households earning less than $10k to 65.1% for households earning more than $150k.

Since compensation aboard a lobster vessel varies according to crew type, the regional impacts of income expenditures were estimated separately for vessel owners/captains, primary crew members, secondary crew members, and tertiary crew members. For each crew type, the average estimated income earned from lobster fishing in 2003 dollars was combined with the average estimated spousal income

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[8] The Bureau of Economic Analysis creates these expenditure patterns for their work on the national benchmark input-output tables. The IMPLAN Pro system provides PCE estimates for nine different household income classes: <10k, 10–15k, 15–25k, 25–35k, 35–50k, 50–70k, 75–100k, 100–150k, and >150k.

[9] Average annual 2004 spousal income levels were estimated for spouses of owners/captains ($18,998) and spouses of primary, secondary, and tertiary crew members ($8,826) using Department of Labor data. These values were assumed to be unaffected by changes in lobster fishing incomes and were obtained by application of data on marriage rates and spousal income levels for the general population using U.S. Bureau of the Census data.

value and then multiplied by the corresponding disposable income rate to determine which of the nine PCE profiles best represented the spending patterns of lobster fishing households. The total estimated disposable income earned from lobster fishing for each crew type was then multiplied by the appropriate PCE profile to distribute the income purchases directly to the industries contained in the PCE vector. These allocated purchase values include expenditures for goods and services that may be produced by industry sectors located outside of the study area, so IMPLAN Pro's RPCs were applied to the values to estimate the amount of each purchase that was supplied by local businesses. These adjusted values reflect the direct effect of the personal consumption expenditures on businesses within the region (*i.e.*, disposable income spending in the region). The values of the direct effects were then applied to the IMPLAN-generated multipliers, which measure the indirect and induced effects, to estimate the regional contribution or total effect of each purchase. The sum of the impacts generated from each purchase indicates the total sales, income, and employment attributable to income expenditures by lobster owners, captains, and crew members in the regional economy.

Results

Bio-Economic Simulations

All of the effort reduction scenarios are estimated to improve the state of the resource, generate higher levels of landings, and increase total fishermen income over time compared to the simulation effects of the comparable status quo resource productivity condition (table 5). The model predicts that maximum total personal income over the long term would be generated with large reductions in total trap numbers under all three of the alternative scenarios. As expected, when the total number of modeled traps fished by the fleet declines from over 59,000 (status quo scenario 1) to 5,600 (scenario 2), 7,430 (scenario 3), and 11,100 (scenario 4), the exploitation rate falls and the state of the resource improves over time. The number of lobsters in the population is projected to rise from 5.5 to 6.1 million individuals and egg production from 40 to 60 million. The average biomass of legal-size lobsters that remains in the water is estimated to rise substantially in all of the alternative scenarios, expanding from 0.1 million lbs. up to a steady-state level of 1.9 million lbs. (scenario 4). Steady-state levels for these biological indicators are obtained after simulating approximately four to five years of productivity. That is, the population of lobsters, egg production, and the average biomass of legal-size lobsters that remain in the water increase each year as the state of the resource improves under the effort reduction scenarios and reaches constant steady-state levels after about four years (figure 2).

Landings (in pounds) are predicted to increase relative to status quo levels, even though the total number of traps fished is estimated to decline by between 500 to 1,000% in each of the alternative scenarios. As the exploitation rate falls with reductions in traps and/or vessels, the predicted increase in the catch per trap haul and the average weight of each landed lobster raises landings above status quo levels. The number of landed lobsters is predicted to decline from 0.8 to 0.5 million in all of the alternative scenarios, but landings increase from 1.1 to 1.4 million lbs. over time as the average size of landed lobsters rises.

When comparing net income under the various scenarios, it should be noted that the conditions experienced by the status quo Area 2 lobster fleet in 2003 are not likely to be sustainable over the long term. Total fleet-wide costs were estimated to exceed revenues in 2003 by approximately $300 thousand. In contrast, total personal

Table 5
Modeled SIMLOB Conditions and Simulation Results

Scenario Number	1 (Status Quo)	2 (Trap Adjustments)	3 (Boat Adjustments)	4 (Trap and Boat Adjustments)
Number of boats	80	80	10	6
Traps per boat	743	70	743	1,850
Fishing days per year	122	122	122	122
Traps hauled per day[a]	267	70	267	267
Minimum legal size (mm)	86	86	86	86
Max traps fished by full-time model fleet	59,452	5,600	7,430	11,100
Lobster population (millions)	5.5	6.1	6.1	6.1
Number of eggs (millions)	40.0	60.0	60.0	60.0
Average biomass of legal size lobsters that remain in the water (million lbs.)	0.1	1.7	1.8	1.9
Landings (million lbs./year)	1.1	1.4	1.4	1.4
Number landed (millions/year)	0.8	0.5	0.5	0.5
Catch per trap haul (lbs./trap hauled)	0.4	2.8	5.2	8.2
SIMLOB avg. weight of lobster landed (lbs.)	1.24	2.7	2.8	2.81
Calculated avg. weight of lobster landed (lbs.)[b]	1.35	2.7	2.8	2.81
Annual fleet revenue (million US $'s/year)[c]	5.0	8.57	8.63	8.65
Total personal income (million US $'s/year)[d]	(0.3)	4.76	7.98	8.21
Fishing jobs per boat[e]	1.5	1.5	4.0	4.0

[a] The average daily haul rate for scenario 2 was set equal to the estimated traps fished per boat since the trap numbers that result from these scenarios are much lower than the numbers reported in 2003.
[b] The average weight of landed lobsters as indicated by SIMLOB is somewhat different than the average weight of landed lobsters as calculated by dividing the landed weight by the number landed. The difference is greatest when the fishing mortality rate is high and most of the landed lobsters are in the first size category that includes the legal size. This difference is presumably the result of SIMLOB's use of size categories. The difference disappears as the average size increases.
[c] Values are in 2003 dollars.
[d] The number of employees per lobster boat was determined exogenously based on the experience of the cooperating fishermen, taking into account the net income levels available to each lobster fishing business under each scenario.

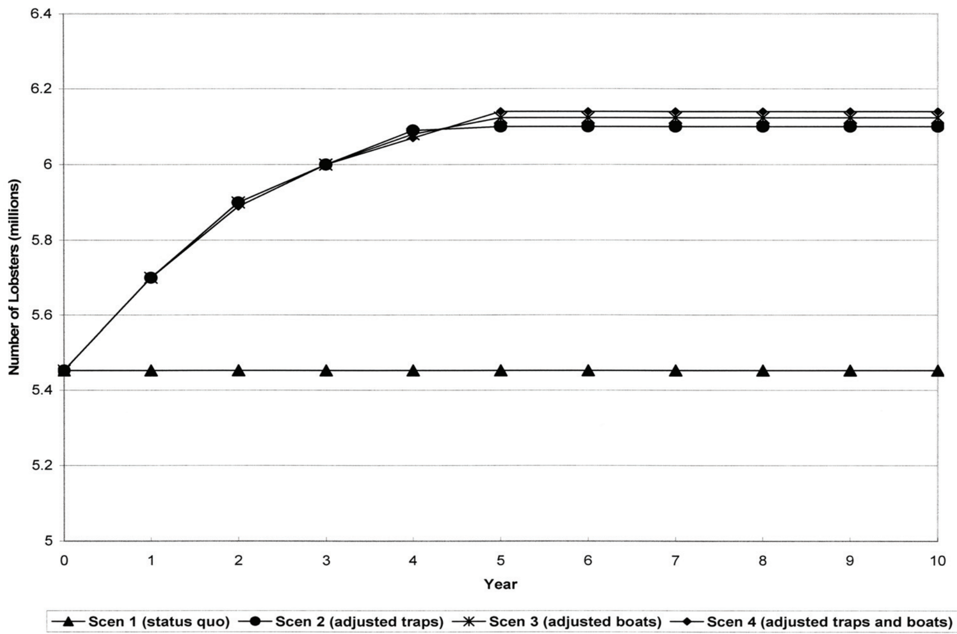

Figure 2. Lobster Population Transition

income is predicted to increase rapidly under the effort reduction scenarios as operating costs decline (*e.g.*, bait, fuel, and trap replacement costs) and resource conditions improve. Model results indicate that the long-run equilibrium levels of total personal income would be 4-1/2 to 8 times the amount realized in 2003 (figure 3). In the first year of the transition, however, total annual net income is predicted to decline for the scenario that reduces the number of traps fished, but maintains the same fleet size (scenario 2). For this scenario, the additional value obtained from the biological gains during year 1 of the transition and the cost savings from reducing fishing effort are not enough to overcome the revenue declines associated with lower overall levels of landings during this time period. Total net income rises rapidly, however, as the resource grows and exceeds status quo levels in the second year of the transition. Total net income exceeds status quo levels in the first year of the transition for the scenarios that consider a reduction in fleet size (scenarios 3 and 4) because of the large cost savings associated with reduction in the numbers of vessels. The highest net income over the long term is generated by allowing the simulation model to choose the combination of both traps and number of boats that maximize total personal income (scenario 4).

The increase in number of traps fished per boat when adjustments in both traps and fleet size are considered (from 743 to 1,850) results from the potential for higher marginal profitability from increased trap numbers compared to increased boat numbers. With the number of fishing days set at 122 and the number of traps hauled per day set at 300, revenue can be increased by adding boats or traps, each of which has associated costs. If traps per boat are limited, each boat may not be able to optimize its inputs, and the highest profits available under those conditions may occur with more boats. If traps per boat are not limited, the highest profits may occur with fewer boats and more traps per boat. The optimum number of traps per boat

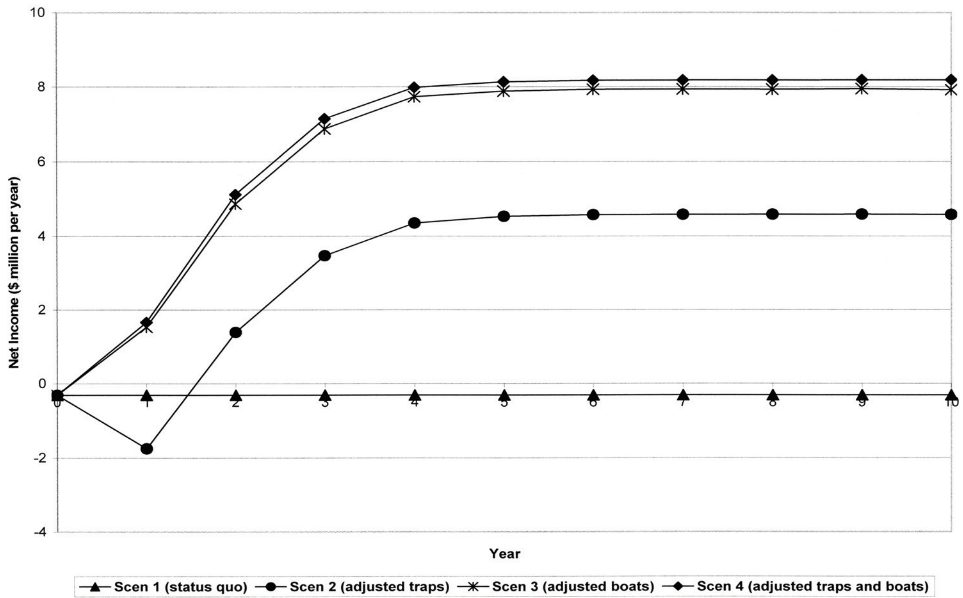

Figure 3. Net Income Transition

depends on the difference between the marginal revenue per trap and the marginal cost per trap. If the number of traps to be hauled in one day is fixed, the only additional cost associated with additional traps is trap depreciation. Trap depreciation is fixed and the absolute value of marginal revenue as a function of soak time changes with the prevailing catch per unit of effort, which varies seasonally. Whereas the number of fishing days per month is much larger during the period when the catch is largest, the marginal benefit from longer soak time is also greater. The relatively high fishing days per month create a relatively short soak time, keeping the fleet on the steep portion of the catch versus soak time curve where the slope is greater than the slope of the cost curve. The high seasonal catch rates raise the revenue curve, increase the absolute value of the marginal revenue, and indicate the potential for higher profits with more traps per fishing business, as long as the slope of the revenue curve remains greater than the slope of the cost curve. Our simulation results correspond with industry trends prior to the imposition of trap limits and with the conclusions reached by Gates (2000) in his analysis of input substitution in a trap fishery.

Input-Output Assessment

The potential economic contribution of lobster harvesting in Area 2 to the overall regional economy, under each of the management scenarios, is summarized in table 6. To help clarify the meaning of the results, the impacts are distinguished by contribution type. The lobster harvesting row shows projected annual sales (*i.e.*, ex-vessel revenues) in 2003 dollars; total annual income earned by owners, captains, and crew members; and total estimated harvesting employment (*i.e.*, total number of captains and crew members). The fleet operating expenditure row shows total sales, income,

Table 6
Total Annual Sales, Personal Income, and Employment Contributions (Direct, Indirect, Induced) of Area 2 Lobster Harvesting in Rhode Island, Barnstable County (MA), Bristol County (MA), and Dukes County (MA) under Different Area 2 Lobster Management Scenarios (2003 dollars)

		Value to Regional Economy		
Scenarios	Contribution Type	Sales ($1,000)	Income ($1,000)	Jobs
Scenario1	Lobster harvesting	4,895	734 [a]	120
(status quo)	Fleet operating expenditures (excludes labor payments)	5,841	2,210	58
	Income expenditures of owners, captains, and crew	797	273	9
	Total	11,533	3,217	187
Scenario2	Lobster harvesting	8,570	4,758	120
(adjusted traps)	Fleet operating expenditures (excludes labor payments)	3,690	1,412	35
	Income expenditures of owners, captains, and crew	4,594	1,547	50
	Total	16,854	7,717	205
Scenario3	Lobster harvesting	8,630	7,980	40
(adjusted boats)	Fleet operating expenditures (excludes labor payments)	655	249	6
	Income expenditures of owners, captains, and crew	7,309	2,461	80
	Total	16,594	10,690	126
Scenario4	Lobster harvesting	8,650	8,206	24
(adjusted traps	Fleet operating expenditures (excludes labor payments)	402	152	4
and boats)	Income expenditures of owners, captains, and crew	7,361	2,481	81
	Total	16,413	10,839	109

[a] SIMLOB predicted that fleet income was actually negative under scenario 1, but it was assumed that owners paid crew at the normal rate.

and employment effects that occur in the economy from direct purchases of goods and services by the lobster fleet and the indirect and induced effects that result from secondary industries in the region purchasing goods and services to meet the production requirements of the Area 2 lobster fleet. Sales represent the estimated annual dollar value of production in the region summed across all industries and is a measure of total economic activity. Income represents the estimated dollar value of wages and salaries (including benefits) and self-employed income earned in the region, and jobs represent the estimated number of total wage and salary employees (both full and part-time), as well as self-employed workers in the region. The third row under each scenario (labeled income expenditures of owners, captains, and crew members) shows the regional sales, income, and employment attributable to the spending of income by owners, captains, and crew members and the indirect and induced effects that take place as spending occurs to meet the demands of the initial income expenditures. The sales, income, and jobs values have the same interpretation as indicated above for the fleet operating expenditure row. The sum of the three rows of impacts represents the full contribution of the lobster harvesting sector to the regional economy and is shown in the final row under each scenario.

The scenario that maintains the status quo fleet size but reduces effort through reductions in the numbers of traps fished (scenario 2) results in the greatest overall contribution to sales ($16.85 million) and employment (205 jobs) in the regional economy. The highest income impacts are generated from the scenario that models simultaneous adjustments to both traps and number of boats (scenario 4; $10.84 million).

Of greater interest is the effect of efficiency improvements relative to status quo conditions modeled in this study. Do the scenarios that improve the efficiency of the lobster fleet increase or decrease the regional economic benefits derived from lobster fishing in Area 2? For the simulations we conducted, total regional sales and personal income are significantly higher for every scenario where the harvesting efficiency of the fleet was improved compared to the "status quo" fleet operation. The regional sales and income effects attributed to the operating expenditures of the fleet decline because production costs decline as the total number of traps set falls from over 59 thousand (scenario 1) to around 5 to 11 thousand in the alternative effort reduction scenarios. However, the increase in harvesting revenues, harvesting earnings, and the regional multiplier effects of those increased earnings in all three of the effort reduction scenarios more than offset the decline in regional sales and income associated with the reduced fleet expenditures.

As harvesting efficiency improves, total regional employment generated by the lobster industry is predicted to increase for the trap adjustment scenario and decline for the remaining two modeled scenarios. The increase can be attributed to a simulated rise in regional income expenditures by lobster owners, captains, and crew members, while the reductions are associated with a decline in harvesting jobs and lower overall operating expenditures within the Area 2 region.

For the trap adjustment scenario, the number of harvesting jobs is assumed to remain constant (120), as fleet size and fishing jobs per boat were set equal to status quo levels. However, the increase in fishing jobs per boat in the two scenarios that simulate reductions in fleet size are not enough to offset the decline in lobster harvesting jobs associated with lower levels of participating vessels. The regional employment effects attributed to the operating expenditures of the fleet decline in all three of the scenarios that improve efficiency because reduced production costs translate into lower expenditures in the region. Nonetheless, as efficiency improves there is a large increase in regional employment attributed to the income expenditures of owners, captains, and crew members. The increase is partly due to the overall rise in income spending as earnings grow with improvements in efficiency, but is mostly due to additional purchases of locally produced goods and services.

Household spending patterns differ greatly from the goods and services purchased to operate a lobster vessel. Lobster fleet expenditures support a number of manufacturing and support businesses that are generally located outside of the study region (*i.e.*, fuel refineries, gear suppliers, electronics manufacturers, maintenance facilities, *etc.*). Personal consumption expenditures support a few of the same industries, but they also support a wide array of retail and service-oriented establishments (merchandise stores, restaurants, hospitals, real estate, *etc.*) that are almost all located within the study region according to the RPC data contained in IMPLAN Pro. Therefore, as lobster incomes rise and production costs decline with improvements in efficiency, more spending remains within the region, creating additional jobs in the economy. The contribution of this increase in spending to regional employment is estimated to support an additional 41 jobs under the trap reduction scenario (relative to status quo levels), 71 jobs under the scenario that reduces the number of participating vessels, and 72 jobs under the scenario that adjusts both traps and boats. These increases are large enough to offset the decline in regional employment resulting from lower operating costs under the trap reduction scenario, but fall short of counteracting the loss in jobs associated with fewer participating vessels and lower fleet expenditures under the remaining two scenarios.

However, the effect of efficiency improvements on total regional employment is not clearly evident from the scenarios modeled in this study. The SIMLOB model predicted lobster businesses were operating at a net loss, on average, under status quo conditions in 2003. If the SIMLOB model predictions are correct, over time the number of harvesting jobs that could be supported by fishery conditions comparable to those in 2003 (status quo) will be lower than shown in table 6. In that case, the regional jobs generated from the rise in income expenditures by lobster owners, captains, and crew members may be large enough to offset the decline in regional employment resulting from lower operating costs and fewer participating vessels as efficiency improves.

As a consequence of the shift in the flow of expenditures from manufacturing and support businesses to retail and service sector establishments, however, the employment structure of the underlying regional economy is estimated to change relative to status quo levels. In addition to the reduction in lobster harvesting jobs estimated for the two scenarios that limit the fleet size, a decline in the demand for lobster bait (*i.e.*, generally herring and mackerel) under all three of the effort reduction scenarios results in fewer jobs associated with the businesses that supply bait to the lobster fleet (*i.e.*, mid-water trawlers and lobster bait dealers; table 7).[10] In contrast, there is an associated increase in retail and wholesale trade jobs at merchandise stores, supermarkets, garden centers, *etc.*, and service-oriented businesses such as restaurants, hospitals, day care centers, legal services, *etc.*, under all three of the effort reduction scenarios.

Discussion

Experience in fisheries around the world has shown that in the absence of direct controls on fishing effort, fishing intensity generally increases if the fishery is considered profitable. This is exactly what happened in the Area 2 lobster fishery during the 1990s, a period of high financial and biological productivity. Productivity began

[10] The majority of the bait used by lobster fishermen in Area 2 is locally landed herring and mackerel purchased directly from mid-water trawl harvesters and wholesale bait dealers. In the absence of a mid-water trawl sector or a wholesale bait dealer sector, bait purchases were allocated to the default commercial fishing sector in IMPLAN Pro.

Table 7
Employment Contributions by Industry Sector

Scenario Number	1 (Status Quo)	2 (Trap Adjustments)	3 (Boat Adjustments)	4 (Trap and Boat Adjustments)
Lobster harvesters	120	120	40	24
Bait suppliers (mid-water trawlers, bait dealers)	11	2	1	1
Agriculture	0	0	1	1
Manufacturing	7	9	5	5
Mining	0	0	0	0
Transportation, communications, and public utilities	2	3	4	4
Construction	1	1	1	1
Retail and wholesale trade	9	13	17	17
Finance, insurance, and real estate	8	11	8	7
Services	27	45	49	49
Government	1	1	1	1
Total	187	205	126	109

to decline after 1999 as a result of a combination of lower resource abundance and high fishing effort. Although the number of active fishermen and traps has also declined in recent years, the fishery has remained overexploited because price increases, financial assistance programs, technological improvements, restrictions in other fisheries, and the "hope of a better tomorrow" continue to attract excessive fishing effort. As long as there is money to be earned, or the expectation that money can be earned, it is in each lobsterman's best interest to increase his or her exploitation of the resource since he or she receives the full benefit of the increase while the costs are spread among all users. This "tragedy of the commons," originally described by Gordon (1954) and later Hardin (1968), is the recipe for disaster that has befallen innumerable fisheries.

The effort control program recently adopted by the ASMFC for Area 2 has the potential to reverse many of the devastating biological and economic consequences associated with this tragedy of the commons. Although limited in scope, results of the effort reduction scenarios simulated in this paper indicate that adjustments in trap numbers and/or the number of boats that fish in Area 2 may have the potential to not only improve the biological condition of the lobster resource, but also increase lobstermen's income and raise the economic importance of lobster harvesting to other businesses in the regional economy without having a substantial effect on overall employment in the economy.

Simultaneous adjustments to both traps and numbers of boats in the analysis generally resulted in higher economic and biological gains over the long-term than adjustments to traps or boats in isolation because of comparatively greater efficiency improvements. Nonetheless, when considered separately, adjustments to the numbers of traps fished per boat or to the numbers of participating vessels also resulted in vastly improved resource and economic conditions for the fleet and the regional economy as a whole. The key element in all of the effort reduction scenarios is a decrease in the total number of traps fished in Area 2.

Reductions in trap numbers in Area 2 also lower the potential adverse impacts of the stationary gear on bottom habitat and reduces the risks of entangling whales and other marine life in lobster fishing lines. In response to reductions in trap numbers, however, lobstermen would likely reduce the number of traps per buoy to increase the attraction radius of a single trap. Despite this possibility, a decrease in the total number of traps fished in Area 2 would result in fewer lines in the water, reducing the potential for impacting bottom habitat and entanglement.

The Area 2 lobster fishery experienced high catch rates and high landings during the 1990s. After experiencing peak landings in 1999, the fishery declined to the point that ASMFC implemented emergency conservation measures in 2003. Our simulation scenarios attempt to capture the level of biological and economic productivity that the fishery has experienced in recent years. Another set of scenarios was calibrated to represent the high productivity conditions that existed in 1999. For reasons of brevity, and to provide guidance that is more relevant to recent conditions, only the scenarios that used 2003 as the status quo are presented in this paper. It should be noted, however, that the general results of rationalization through adjustments in the total number of traps fished or in the number of participating vessels for the two fishery conditions were identical in form but different in magnitude. The potential economic gains were determined to be considerably higher in absolute terms for the higher productivity scenarios than for the less productive fishery conditions.

The regional input-output model used in this study suffers from a number of limitations that had a direct effect on the impact estimates. First, the input-output study area was restricted to the southern New England coastal economy. While this isolates the important multiplier effects within the regional economy, the small study area invariably has a high level of leakage. Leakages are expenditures made for goods and services manufactured outside of the study area which are not, in turn, re-spent within the region. Thus, businesses located in areas other than southern New England could also be impacted (both positively and negatively) by an Area 2 effort reduction program. Second, it's also probable that at least some of the displaced effort in the scenarios that modeled reductions in the number of participating lobster vessels will switch to another area, such as the inshore northern New England area (Area 1). Although license limitations will constrain much of the switching behavior in this case, movement of displaced effort to areas already stressed by overfishing and overcapitalization could potentially drive down profits in those areas and thus the resulting economic impacts generated from fishing in those areas. A broader input-output model that includes coastal counties located in northern New England, for example, may be more appropriate if the level of switching behavior and its associated effect on overall landings can be anticipated. However, if the input-output study area is too large, the modeled effects could be masked by extraneous economic activity. The use of applied or computable general equilibrium models may provide a more complete assessment of switching behavior since these models address some of the aforementioned limitations of input-output appraisals.

The findings of this research are not definitive. Adjustments were simulated for the average number of traps fished and the number of participating vessels. The average fishing days per year and the number of traps hauled per day were assumed to remain constant. These assumptions mean that both nominal and effective effort decline in the same proportion. However, changes in fishing practices may result in changes in effective effort even though nominal effort reflected in numbers of vessels and traps may remain the same. These effects were noted by Clark (1980) and have been observed in other lobster trap fisheries (Bowen 1994; Gates 2000) as well as other fisheries (Wilen 1979; Homans and Wilen 1997; Branch *et al.* 2006). The implication of relaxing these assumptions is uncertain. Simulation model results indicate that altered fishing practices, such as hauling traps more than once per day, would still result in economic efficiency gains and positive regional economic impacts. Nonetheless, the economic gains dissipate the greater the ability to counteract reductions in nominal effort with changes in effective effort.

In addition to holding the traps and number of participating full-time vessels constant in each scenario, landings and effort for the part-time Area 2 fleet were assumed to remain the same. However, the substantial improvements in profitability to full-time operators may be expected to attract additional effort from part-time operators, if the management system does not prevent such an increase. Incorporating the part-time fleet in the simulation model may result in more rapid dissipation of economic gains than noted above, since part-time operators could increase effort simply by increasing the amount of time spent fishing.

The policy scenarios developed herein likely provide best case (or near best case) results since the combination of traps and/or boats modeled in each scenario maximize long-term profits and are acknowledged to omit some of the potential sources of benefit dissipation associated with the Area 2 lobster fishery as it is managed today. Despite these limitations, we show that there is an important link between improvement in profitability and net fishing income and the regional economy even as the number of participating vessels or amount of purchased input is reduced. That is, in spite of strongly held perceptions to the contrary, losses of income and jobs in fishing and fishing-related sectors may be more than offset by gains in other sectors through carefully crafted fishery management policy in Area 2 or elsewhere. The magnitude and timing of these gains would depend on how quickly fishing incomes would improve, as well as the structure of the regional economy. The former depends on how the resource would respond to reduced effort, while the latter depends on the difference between how much of the inputs purchased by commercial fishing and fishing-related businesses are produced within the region (the indirect impacts) as compared with the regional output of goods and services purchased by households. Of course, the desirability of any such changes in the underlying structure of a regional economy would need to be considered. Indeed, in the analysis presented here, retail and service sector employment expanded at the expense of lobster harvesting jobs under two of the modeled scenarios.

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