Applying a Bioeconomic Model to Recreational Fisheries Management: Groundfish in the Northeast United States

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ABSTRACT

Recreational fisheries regulations frequently consist of possession limits, size limits, and seasonal closures that constrain the ability of recreational fishermen to catch or land fish. It is difficult to predict how these regulations will influence angler participation and recreational fishing mortality. This research integrates a utility-theory consistent model of demand for recreational fishing trips with an age-structured stock dynamics model to provide policy relevant advice to managers of the groundfish fishery in the Northeast United States. The recreational cod and haddock regulations implemented in 2014 have high costs in terms of foregone angler welfare and minimal positive impacts on stock conditions after three years. The ability of policies that generate large amounts of discarding, like high minimum size limits, to meet conservation objectives are also found to be quite sensitive to assumptions about the recreational discard mortality rate.

Key words: Bioeconomic models, fisheries management, fisheries policy, recreational fisheries management, valuation.
JEL Codes: Q22, Q26, Q28, Q57.

INTRODUCTION

Recreational fisheries regulations frequently consist of possession limits, size limits, and seasonal closures that constrain the ability of recreational fishermen to catch or land fish. Predicting how these regulatory policies will affect anglers, fishing mortality, and future stock levels remains challenging. Policymakers have often been forced to evaluate the economic and biological consequences of proposed management measures without a good understanding of how the regulations will affect recreational effort. This may lead to ineffective regulations that fail to meet objectives of fishery management plans (MAFMC 2013; GMFMC 2013).

In the Northeast US, the New England Fisheries Management Council (NEFMC) sets fisheries policy for federally managed fisheries, and the National Marine Fisheries Service (NMFS) implements the corresponding fishing regulations. In 2013 and 2014, a bioeconomic model was used to

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determine recreational fishing regulations in the Gulf of Maine (GoM) groundfish fishery (79 *Federal Register* 22419–21 [NOAA 2014a]). Management of groundfish in the Northeast US has proven both difficult and contentious (Hennessey and Healey 2000; Brodziak et al. 2008). At the end of 2013, GoM haddock was experiencing overfishing and GoM cod was both overfished and experiencing overfishing (NMFS 2014). Reductions in fishing mortality for both stocks were required to meet the mandates of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

The recreational groundfish fishery is pursued by for-hire and private boat anglers and is an open-access fishery with minimal monitoring. Recreational regulations are designed to ensure that the annual catch limits (ACLs) for the recreational sector are not exceeded for any of the groundfish species. In this article, we describe the integrated bioeconomic simulation model of the recreational groundfish fishery that was used to evaluate recreational fishery policies considered in 2014. We also discuss the challenges involved with using the simulation model for fisheries management. Specifically, the time lags in the availability of scientific information, uncertainties in that information, and institutional limitations of the current management system can be obstacles to using this modeling approach to support tactical policy decision-making.

The economic component of the model is a recreational demand model that is parameterized with a choice experiment (CE) survey. Angler effort is a function of trip costs, trip length, and expectations about landings and discards.[1] Landings and discards on a trip are dependent on angler selectivity, catch-per-unit-effort, recreational fishing regulations, and stock structures of fish. The stock structures of fish are modeled using an age-structured fish stock-dynamics model. The integrated model is characterized by two-way feedback loops between fish stocks and angler participation. Participation, angler selectivity, stock sizes, and regulations jointly determine recreational fishing mortality which, in turn, affects both future stock levels and future recreational fishing outcomes.

We calibrate the model by setting the number of choice occasions in each wave to match the 2013 effort given the prevailing stock and regulatory conditions. We simulate for three years (2014–2016) under alternative recreational policies to examine how changes in recreational policies affect angler welfare, catch, and biological stock conditions. Uncertainty in initial stock conditions and natural variation in recruitment are addressed through Monte Carlo simulation. We find that while the alternative fisheries policies considered in 2014 lead to large differences in recreational fishing mortality and angler welfare, projected stock levels of cod and haddock were minimally sensitive to the policies that were evaluated. In particular, the regulations implemented by NMFS in the 2014 fishing year (May 1–April 30) to comply with the statutory requirements of the MSFCMA were found to have high costs in terms of foregone angler welfare with minimal effects on stock conditions three years in the future.

ECONOMIC SUB-MODEL: ANGLER DEMAND FOR RECREATIONAL FISHING TRIPS

Fenichel, Abbott, and Huang (2013) note that fisheries scientists have typically constructed models that contain links between angler effort and fishing mortality (Beard, Cox, and Carpenter 2003; Post, Mushens, and Sullivan 2003; Post et al. 2003, 2008), but are not based on utility maximization and therefore not likely to be robust to changes in incentives or management. Conversely, economists often abstract away from the biological intricacies in favor of structural, theoretically

1. "Landings" refers to fish that are retained; "discards" refers to fish that are returned to the ocean. "Catch" is the sum of landings and discards. "Removal" is the sum of landings and discards that die.

consistent models. This is particularly true in economic studies of recreational fishing; in contrast, models of commercial fisheries frequently pair theoretically consistent models of economic activity with realistic biological models (see Holland 2000; Kahui and Alexander 2008; Smith, Zhang, and Coleman 2008). Studies of recreational fishing frequently examine the value of adjustments to possession limits without describing how these affect biomass of the managed stock (Carson, Hanemann, and Steinberg 1990; McConnell, Strand, and Blake-Hedges 1995; Oh et al. 2005; Stoll and Ditton 2006; Whitehead et al. 2011). Similarly, the economic effects of marginal changes in trip quality, measured by objective changes in historic catch or expected catch rates, are often evaluated with minimal explanation of how those changes would occur (Kaoru 1995; Schuhmann 1998; Whitehead and Haab 1999; Gillig et al. 2003; Abbott and Fenichel 2013). A notable exception is the bioeconomic model of recreation developed by Massey, Newbold, and Gentner (2006), which examines the effects of changes in water quality on recreational anglers through changes in catch rates.

To assess the potential success of proposed policy measures requires a predictive model that links angler participation to changes in both management measures and stock levels. McConnell, Strand, and Blake-Hedges (1995) and Schuhmann (1998) estimate expected catch as a function of stock levels, which permits welfare evaluation of changes in stock levels, but not evaluation of the policies used to achieve those changes. Theoretical models of possession limits and minimum size limits were developed by Anderson (1993) and Homans and Ruliffson (1999), respectively. Woodward and Griffin (2003) (WG) synthesize those theoretical models and develop an empirical model that also incorporates stock conditions. One of the theoretical findings by WG is that a possession limit is no worse than a minimum size limit at reducing fishing mortality. WG pair their theoretical model with an empirical simulation in which stock conditions are constant within a fishing year and demand for trips is parameterized by estimating a model in which the number of trips taken is a function of price, income, landings, experience, and boat ownership. When discard mortality rates are low, most policy combinations lie on or near the efficient frontier of biomass and welfare. However, when discard mortality rates are high, policies with high minimum sizes become increasingly inefficient as large amounts of discarded fish are released dead. Due to data limitations, WG's model implicitly assumes that discards have zero marginal value to anglers and, therefore, zero impact on angler participation. Jarvis (2011) relaxes this assumption by parameterizing recreational demand using a CE in which anglers make participation decisions based, in part, on expectations about both landings and discards. Furthermore, the Jarvis (2011) model allows minimum size limits and stock composition to interact to determine landings and discards. The model used here builds on the bioeconomic model of Jarvis (2011) by permitting anglers to selectively harvest fish, allowing for realistic resolution of the uncertainty in landings and discards at the time the participation decision is made, and including a model of stock dynamics that permits forecasting future stock sizes.

Discrete choice models are commonly employed to examine recreational fishing behavior (Aas, Haider, and Hunt 2000; Carter and Liese 2012; Lew and Larson 2012; Shideler et al. 2015). The discrete choice model employed here follows Jarvis (2011) and provides the foundation of the behavioral model for recreational anglers. The utility function for recreational anglers is specified so that regulations affect angler's expected utility indirectly by changing the way an angler sorts catch into landings and discards:

$$EU = E[V(landings, discards, OTA) + \varepsilon], \tag{1}$$

where OTA includes other trip attributes such as costs or trip length, and ε are unobservable components of utility. An angler maximizes expected utility by choosing whether or not to take a trip.

The effects of alternative recreational fisheries policies on landings and discards will depend on the size structure of the fish stock. A minimum size limit affects the way that fish will be sorted into landed and discarded fish. If size limits are high and fish are small, then small changes in the size limits will have minimal effects on utility and participation. In this case, there are relatively few "marginal" fish (fish that would be landed under one policy but discarded under another). The same change could have large effects on utility and participation if the size structure of the fish stock were different and there were many "marginal" fish. Similarly, when a possession limit is high relative to typical catch on a trip, then marginal changes in possession limits will have small effects on utility or participation.

CE surveys are frequently used to estimate the effects of changes in regulations when market data are inadequate or nonexistent. A CE survey administered in conjunction with NMFS' Marine Recreational Information Program[2] (MRIP) in 2009 was used to estimate parameters of the recreational anglers' utility function. All anglers intercepted in Maine, New Hampshire, and Massachusetts were asked to participate in a voluntary follow-up mail survey. Anglers who agreed to participate in the follow-up were sent mail questionnaires using a modified Dillman Tailored Design (Dillman 2000).[3] A total of 2,039 surveys were mailed to anglers living in Maine, New Hampshire, and Massachusetts, and 775 completed mail surveys were returned (38% response rate). Each survey contained eight choice task questions in which anglers were asked to compare attributes of two different fishing trips (Trip A and Trip B) and either select their preferred trip or "opt-out" of saltwater fishing. The trip attributes include bag and size limits for GoM cod and haddock, the number of legal- and sublegal-sized fish caught of each species, the number of other types of fish that were legally kept, trip length, and trip cost (a sample survey is shown in online-only appendix; further detail can be found in Jarvis (2011)). The attribute levels contained in the surveys were intended to represent historical and potential future values. The cost and trip length levels were based on angler expenditure data (Gentner and Steinback 2008) adjusted by feedback from focus groups.

Because diminishing marginal utility of landings and discards is likely, a nonlinear-in-catch functional form is used (Lipton and Hicks 2003; Hicks, Haab, and Lipton 2004; Haab, Hicks, and Whitehead 2005; Daw 2008). Therefore, the utility derived by angler n for trip option j is specified as:

$$\begin{aligned} U_{jn} &= V_{jn} + \varepsilon_{jn} \\ &= \beta_{n1}\sqrt{\mathit{cod\ landed}_{jn}} + \beta_{n2}\sqrt{\mathit{cod\ discarded}_{jn}} + \beta_{n3}\sqrt{\mathit{haddock\ landed}_{jn}} \\ &\quad + \beta_{n4}\sqrt{\mathit{haddock\ discarded}_{jn}} + \beta_{n5}\left(\mathit{trip\ length}_{jn} * \mathit{for\ hire}_{n}\right) \\ &\quad + \beta_{n6}\left[(\mathit{trip\ length.})_{jn} * \mathit{for\ hire}_{n}\right]^2 + \beta_{n7}(\mathit{opt\ out})_{jn} + \beta_{8}(\mathit{trip\ cost})_{jn} + \varepsilon_{jn}\,. \end{aligned} \tag{2}$$

Equation 2 is estimated using a mixed logit model (McFadden and Train 2000) in which the β_1 through β_7 parameters are allowed to be normally distributed, while β_8 is treated as fixed.[4] The

2. The MRIP is an integrated series of angler surveys coordinated by NMFS in order to provide reliable estimates of marine fishing effort, catch, and participation.

3. Intercept brochure, mail instrument three to six weeks later, postcard reminder two weeks after first mailing, and second mailing of survey instrument four weeks after first mailing.

4. As part of the model specification process, linear and quadratic models were estimated using both conditional and mixed logits. While the quadratic model fit the data reasonably well, it generated the implausible result that landed cod reduced utility at

Table 1. Mixed Logit Estimation Results

Utility Function Parameter	Estimate (standard error)	Standard Deviation Parameter (standard error)
$\sqrt{cod\ landed}$	0.33858***	0.1848
	(0.03822)	(0.20135)
$\sqrt{cod\ discarded}$	0.11128***	0.19278
	(0.02701)	(0.15005)
$\sqrt{haddock\ landed}$	0.33558***	.26932*
	(0.03444)	(0.15797)
$\sqrt{haddock\ discarded}$	0.09624***	0.10108
	(0.03008)	(0.22859)
trip length $*$ for hire	0.02593	0.00603
	(0.02611)	(0.05179)
(trip length)^2 $*$ for hire	–3.51E–005	0.00428
	(0.00211)	(0.00352)
opt-out	–1.67608***	2.55826***
	(0.38518)	(0.47826)
trip cost	–.00581***	N/A
	(0.00031)	N/A
No. Obs.	4,966	
Log-likelihood (LL)	–4,908	
LL(0)	–6,884	
McFadden's LRI	0.2871	
AIC	9,846	

***, **, * indicate significance at the 1, 5, and 10% levels respectively.

trip length attribute was only included in surveys of for-hire anglers; shore and private boat-intercepted anglers received a slightly different version of the CE survey that did not include this attribute. To account for this, the trip-length variable is interacted with a dummy variable for for-hire boat anglers. Linear and quadratic terms for trip length are included to accommodate the possibility of diminishing marginal utility of trip length. The estimated parameters generally have expected signs and levels (table 1). The significance of the standard deviation parameters suggests moderate preference heterogeneity for discarding haddock and stronger heterogeneity for the opt-out parameter. We also find moderate evidence that the "haddock discarded" parameter should be treated as random and strong evidence that the "opt out" parameter should be treated as random. In this fishery, recreational anglers value landing fish more than discarding fish and, in particular, value landing cod slightly more than landing haddock. Trip cost and the opt-out parameter are negative, and trip length does not affect angler utility. For choice occasion i, the compensating variation (CV) for a change in trip outcomes is given by:

$$CV_i = -\frac{1}{\beta_8}\left(\ln\left[1 + e^{V_1}\right] - \ln\left[1 + e^{V_0}\right]\right), \tag{3}$$

where V_0 and V_1 are the initial and final levels of observable indirect utility (for example, Newbold and Massey 2010). The estimated parameters also allow us to compute the probability that

fairly low levels of landings (eight fish). This may be a result of the survey design process, which used a main effects design mechanism. Full econometric results are available from the authors.

an angler facing a choice occasion will take a recreational trip conditional on the number of landed and discarded fish of each species.

BIOLOGICAL SUB-MODEL: AGE-STRUCTURED POPULATION DYNAMICS

NMFS conducts stock assessments to determine the biomass of a stock of fish. The key outputs of the stock assessment process include fishing mortality and estimates of "terminal-year" stock size.[5] Because both the stock assessment and policy process can take a long time to complete, probabilistic projections are used to bridge the gap between the terminal-year and the year fisheries managers are setting fisheries policy. NMFS also conducts operational assessments which incorporate newly collected scientific data in an existing model to generate updated estimates of stock size. The GoM cod stock assessment (NEFSC 2013), haddock stock assessment (NEFSC 2008), and haddock operational assessment (NEFSC 2012) were used to parameterize the age-structured, discrete-time fish stock model (Brodziak, Rago, and Conser 1998). This age-structured projection framework is currently being used by NMFS in the Northeast United States to provide short- and medium-term projections for a variety of fish stocks, including both cod and haddock.

We briefly review the standard fishery population dynamics component before describing the modifications that were made to integrate the fisheries sub-model with the economic sub-model. For notational simplicity, the subscripts for species (cod and haddock) are omitted. The number of fish in age class a and year y, $N_a(y)$, is assumed to decay exponentially within a year, and this decay is partitioned into instantaneous natural and fishing mortality rates, M_a and F_a. In the standard model, M_a and F_a occur simultaneously and "competitively" (Ricker 1975). A "plus" age-class, A, includes all fish aged A and older. The following three state-transition equations represent the age-class transitions for the age-structured population and the relationship between spawning stock biomass (SSB) and recruitment of age 1 fish in the subsequent year:

$$N_{a+1}(y+1) = N_a(y)e^{(-M_a-F_a)} \quad \forall \quad a = 1, \ldots, A-2 \tag{4}$$

$$N_A(y+1) = N_{A-1}(y)e^{(-M_{A-1}-F_{A-1})} + N_A(y)e^{(-M_A-F_A)} \tag{5}$$

$$N_1(y+1) = G(SSB(y)). \tag{6}$$

Two critical modifications to this standard model of fish dynamics are made. First, the stock is modeled at a bimonthly time step, corresponding to the MRIP survey wave by indexing years (y) and waves (w). Fish transition to the next age class at the end of the 6th wave (i.e., surviving age-a fish turn into $a+1$ fish and age-1 fish are born). Second, fishing mortality for each age-class is partitioned into a commercial mortality rate (CM_a) and recreational removals (R_a) expressed in numbers of fish. For computational tractability, the recreational removals in a wave are assumed to occur in a discrete pulse after commercial and natural mortality has occurred. Therefore, equations 4–6 are modified to:

$$N_a(y, w+1) = N_a(y, w)e^{\frac{(-M_a-CM_a(y,w))}{6}} - R_a(y, w) \;\; \forall \;\; a = 1, \ldots, A; \;\; w = 1, \ldots, 5 \tag{7}$$

5. Terminal year refers to the final year for which the stock structure is estimated.

$$N_a(y+1,1) = N_{a-1}(y,6)e^{\frac{(-M_a - CM_a(y,w))}{6}} - R_{a-1}(y,6) \;\; \forall \;\; a = 2, \ldots, A-1 \tag{8}$$

$$\begin{aligned} N_A(y+1,1) = {} & N_{A-1}(y,6)e^{\frac{(-M_A - CM_{A-1}(y,6))}{6}} - R_{A-1}(y,6) \\ & + N_A(y,6)e^{\frac{(-M_A - CM_A(y,6))}{6}} - R_A(y,6) \end{aligned} \tag{9}$$

$$N_1(y+1,1) = G(SSB(y)). \tag{10}$$

SSB in year y is computed as the fraction of biomass that is reproductively mature at the end of wave 2:[6]

$$SSB(y) = \sum_{a=1}^{A} p_a \omega_a N_a(y), \tag{11}$$

where p_a is the fraction of each age-class that is reproductively mature, and ω_a is the average weight of an age-a fish.

Our policy analysis of how regulatory changes affect anglers, fishing mortality, and future stock levels links the fish stocks (equations 7–10) to the anglers' utility function (landed and discarded fish in equation 2). To build this link, three additional pieces of information are necessary. Fishing regulations are based on length and the population model is age-structured; therefore, we translate the age structures of fish into length structures. Second, we construct angler selectivity, based on historical catch and length structures, to account for targeting behavior by anglers. This allows the catch of fish to be responsive to changes in the stock of fish. For example, a larger number of small fish in the ocean would lead to higher amounts of catch and discards of these fish. Third, we construct catch-per-trip measures.

NMFS bottom-trawl survey data from 2011–2013 are used to translate from age to length. We define P_{al} as the proportion of age-a fish that are length l and Q_{al} as the proportion of length-l fish that are age-a. These can be used to convert between an age structure and a length structure:

$$N_l = \sum_{a=1}^{A} N_a P_{al} \tag{12}$$

$$N_a = \sum_{l=1}^{L} N_l Q_{al}. \tag{13}$$

A LOWESS (Cleveland 1979) with bandwidth = 0.5 is used to smooth both P_{al} and Q_{al}, and these smoothed versions are used in the model (figure 1 illustrates P_{al} for both species).

Angler selectivity, also based on length structures, accounts for targeting behavior. We assume recreational effort within a wave is homogenous and that catch of length l fish (C_l) follows the Schaefer (1954) catch equation:

$$C_l(y,w) = q_l(w) N_l(y,w) E(y,w), \tag{14}$$

6. The stock assessment models compute SSB for both stocks on April 1 of each year. Because this date falls within MRIP wave 2, we compute our SSB measure at the end of wave 2 for convenience. This implies that, all things equal, our computed SSB will be lower than the correct measure by the mortality from all sources that occurs during the month of April.

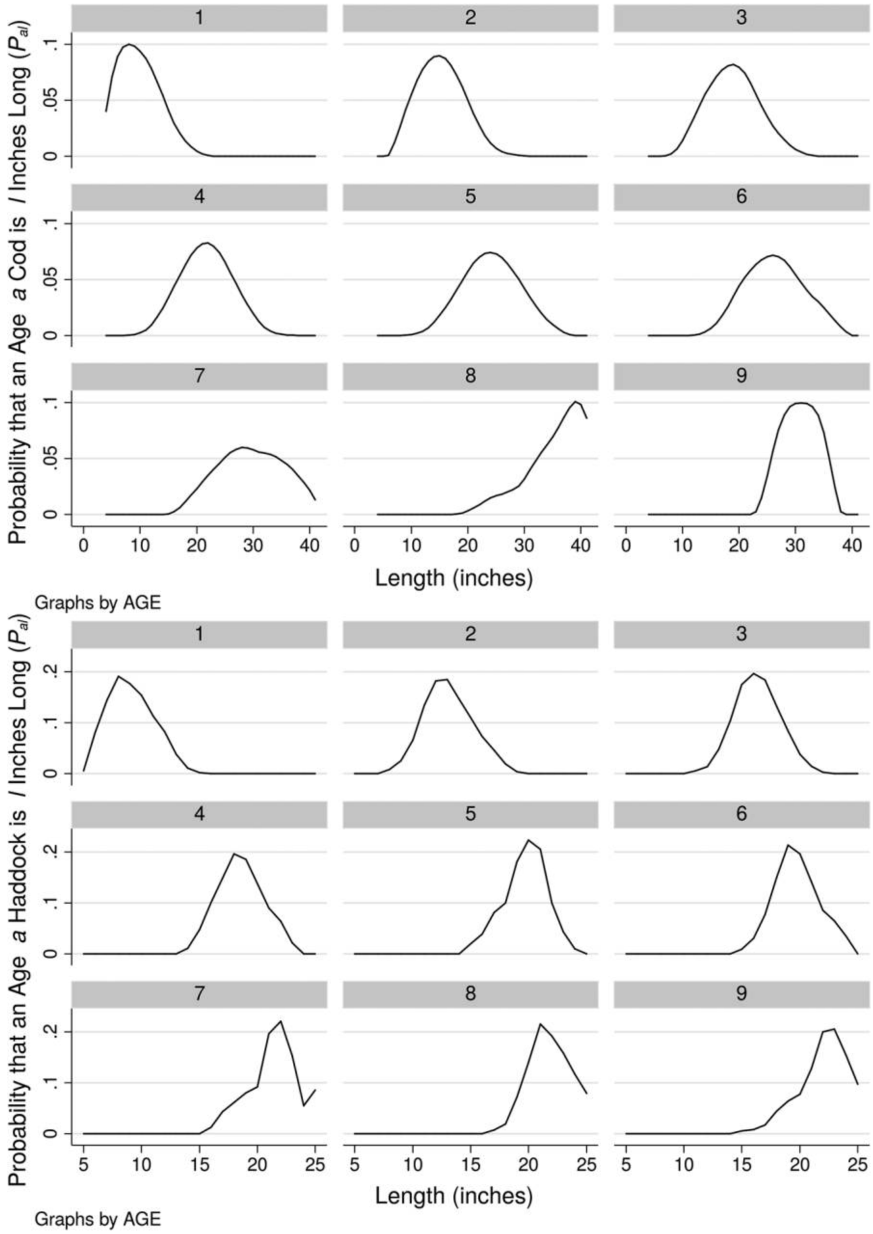


Figure 1. Age-length Conversions, P_{al}, for (a) GoM Cod and (b) GoM Haddock

where C_l is catch (landings plus discards) of length l fish, q_l is recreational selectivity, N_l is the number of length l fish in the ocean, and E is the total number of recreational trips. Equation 14 can be rearranged to compute recreational selectivity for the representative trip in wave w:

$$q_l(w) = \frac{C_l(y, w)}{N_l(y, w)E(y, w)}. \tag{15}$$

To account for prevailing management policies, angler targeting behavior, and stock conditions, MRIP data from the most recent calendar year (2013) are used to construct C_l at the wave level. Numbers-at-length (N_l) are constructed by converting the projected 2013 age structures using equation 12. Recreational selectivity is computed from equation 15, smoothed using a LOWESS, and normalized so that the most intensively selected length has a selectivity of 1.

The wave 4 selectivity for cod and haddock (figure 2) are illustrative of the recreational selectivity in the other waves. In this fishery, anglers are avoiding small fish; this is expected because a minimum size limit has been in place for many years. Anglers also are unable to catch very large

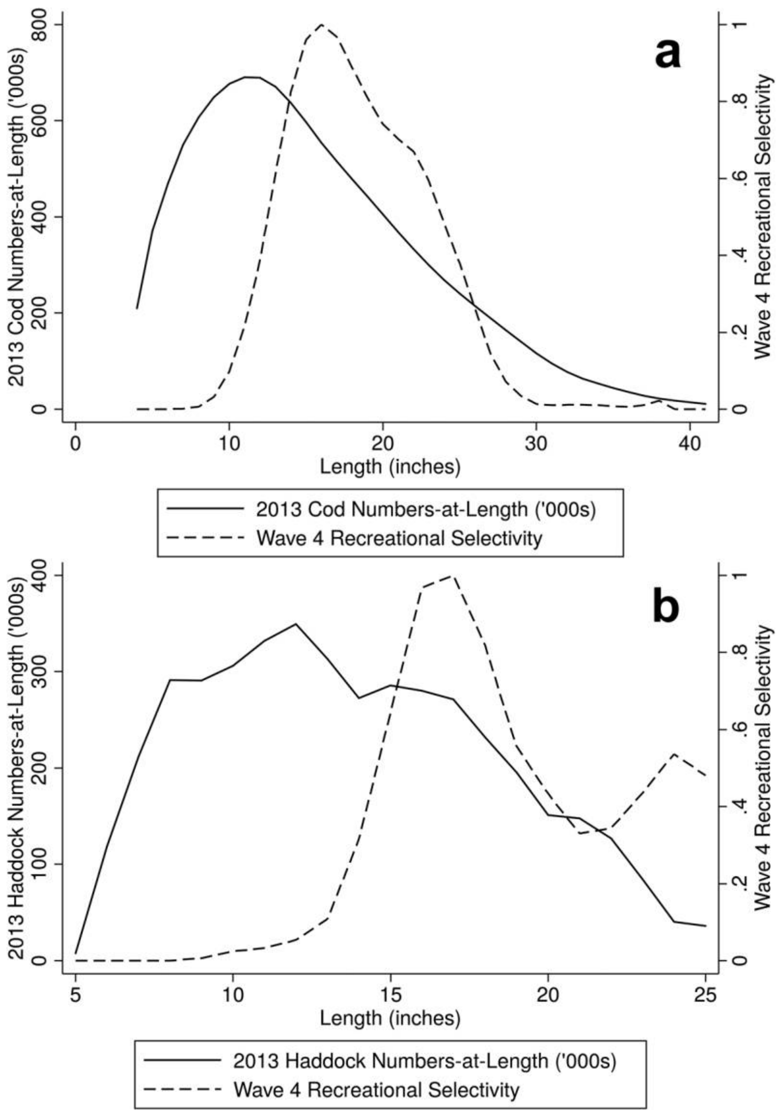


Figure 2. January 1, 2013 Numbers-at-Length and Recreational Selectivity in Wave 4 for (a) GoM Cod and (b) GoM Haddock

fish even though catching those fish is quite desirable; selectivity for large cod is very low relative to selectivity for medium-sized (16–20″) cod. Similarly, proportionally fewer large haddock are caught relative to medium-sized haddock. This may be due to gear and location choices made by anglers or reflect simply the fact that the largest fish are harder to catch.

With $q_l(w)$ constructed for each wave from historical data, it is possible to compute C_l from the catch equation for any stock structure, $\tilde{N}_l$. Dividing C_l by total catch ($\Sigma_l C_l$) produces a probability mass function of the length of caught fish, conditional on $\tilde{N}_l$:

$$g(l) = Prob[length = l] = \frac{C_l}{\sum_{l=}^{L} C_l} = \frac{q_l \tilde{N}_l}{\sum_l^L q_l \tilde{N}_l}. \tag{16}$$

Equation 16 illustrates how changes in the length composition of a fish stock cause changes in the length distribution of fish that are caught on a recreational trip.

We use MRIP data from 2013 to construct catch-per-trip measures. We compute a probability mass function of catch-per-trip for each species based on trips that "targeted" or "caught" either species in each of the six waves:

$$f(c) = Prob[catch] = \frac{\#\ of\ trips\ that\ caught\ c\ fish}{total\ trips}. \tag{17}$$

These distributions were truncated at 40 cod and 35 haddock; values of catch higher than those maximums were set to 40 and 35, respectively. This affected just under 1% of trips encountering each species. Figures 3a and b illustrate the catch-per-trip probability mass functions for wave 4 that have been smoothed with a LOWESS.

Commercial fishing mortality is set based on recent historical use patterns in NMFS mandatory dealer reporting data; the average landings in 2011 and 2012 are used because final 2013 data for the commercial fishery was not yet available. Commercial landings are aggregated into bimonthly waves then divided by total landings to compute the wave level fraction of commercial landings. This is then combined with GoM sub-ACLs for the commercial fishery to compute commercial landings, $L(y,w)$, in the future. In fisheries science models, it is common to decompose CM_a into a scalar and vector S_a, where S_a is known fishery selectivity-at-age of the commercial fleet and normalized so that the $S_a = 1$ for the age-class that experiences the highest rate of commercial fishing mortality.[7] We then solve for CM using function iteration:

$$L(y,w) = \sum_{a=1}^{A} \omega_a * CM * S_a * N_a. \tag{18}$$

This allows us to compute the age-structure of commercial landings (CM_a).

The instantaneous natural mortality rate (M_a) is set to 0.2 for all age classes of both species (NEFSC 2012, 2013). The discard mortality rate is parameterized from the appropriate stock assessment and set to 30 and 0% for cod and haddock, respectively (NEFSC 2012, 2013). The relationship between SSB and recruitment (equation 6) is not well established for either species, and investigation of the stock-recruitment relationship has been identified as a research priority for both

7. This process may seem unnecessarily complicated; however we do this to maintain consistency with standard fisheries science models, which assume that sources of mortality occur simultaneously and "competitively." Because this model assumes recreational fishing occurs after commercial and natural mortality, the number of fish that die due to natural mortality will be slightly higher than in standard fisheries science models.

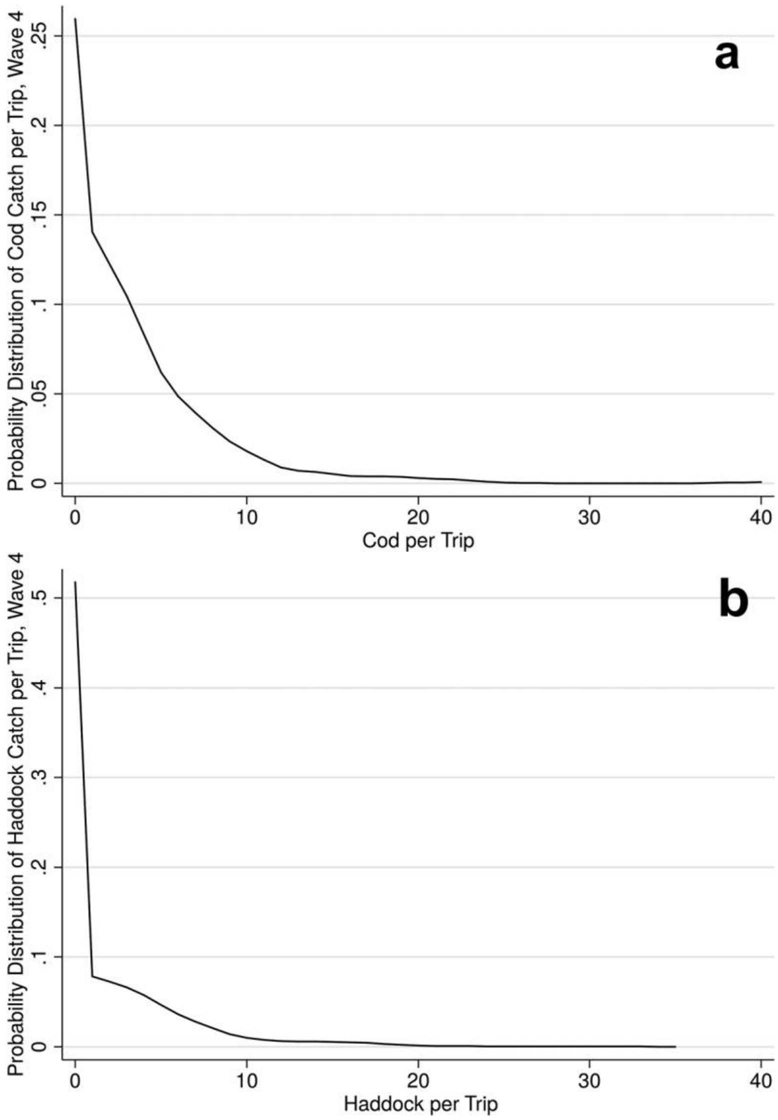


Figure 3. Probability Distribution Function for Catch-per-Trip in Wave 4 for (a) GoM Cod and (b) GoM Haddock

of these species (NEFSC 2013, 2014). For haddock, recruitment in a year is assumed to be independent of SSB and is randomly drawn from an adjusted distribution of historical recruitment. For cod, recruitment is weakly dependent on SSB; when SSB is below a critical point (6,300 mt), recruitment is adjusted proportionally downward. The method described by Brodziak, Rago, and Conser (1998) is used to bridge the gap between the terminal years in the stock assessments and the beginning of the 2014 fishing year.

To summarize, equations 12, 16, 17, and 18 contain the link between the stock dynamics model (equations 7–11) and the model of individual behavior. Equation 12 converts the age-structure of each stock into a length-structure, equation 16 describes the length distribution of caught fish, equation 17 describes the catch-per-trip, and equation 18 describes commercial removals. To complete our policy analysis, the final task is to link individual behavior (equation 2) back to the stocks of fish, which we describe in the next section.

BIOECONOMIC SIMULATIONS AND RESULTS

INTEGRATING THE SUB-MODELS AND CALIBRATION

Recreational fishing activity is simulated at the angler's choice occasion then aggregated to the wave level. Anglers make the decision to take a trip before catch is known; to properly account for the resolution of this uncertainty, we use a multi-part fishing process to independently simulate anticipated and realized outcomes. A choice occasion is simulated by first randomly drawing trip-specific variables (trip length, cost, and mode) based on MRIP data and previous estimates of costs (Gentner and Steinback 2008). After the trip-specific variables are assigned, a multi-part fishing process is used to simulate anticipated landings and discards. Not all anglers comply with fisheries regulations. For example, approximately 7% of the sub-legal cod and 8% of the sub-legal haddock that were caught were landed in 2013.[8] This non-compliance is included in the model by assigning a fraction of choice occasions as non-compliant. All encountered fish, up to the possession limit, on these choice occasions are landed.

After assigning costs and compliance, we simulate anticipated catch. First, a maximum number of cod is randomly and independently drawn based on the catch-per-trip distribution, *f(c)*. Lengths of individual cod are independently and randomly drawn from the probability distribution function, *g(l)*. Finally, the length of each cod is checked against the minimum size limit, and all legal-sized fish are retained. The angler is assumed to stop catching cod if either (1) the possession limit for cod is reached or (2) the maximum number of caught cod is reached. This is repeated independently for haddock to construct the anticipated landings and discards for each species on a choice occasion. The anticipated landings and discards are used to construct the probability that a trip occurs and the WTP corresponding to that choice occasion. The three-step fishing process is repeated to construct realized landings and discards that result from each choice occasion.

The landed and discarded fish are combined with other trip attributes for each choice occasion and the estimated parameters in equation 2 to predict the probability that choice occasion k will result in a trip, $\hat{p}_k$. Following Train (2003), the predicted probability is summed across all choice occasions to predict the total number of trips that are taken in a bi-monthly wave. The realized length structure of landed cod is constructed by summing the probability-weighted landings-at-length for each of the T-choice occasions in that wave:

$$Cod\ Landed_l = \sum_{k=1}^{T} \hat{p}_k * number\ of\ length\ l\ cod\ landed_k. \tag{19}$$

The length structures for discarded cod, landed haddock, and discarded haddock are computed similarly. The resultant length structures of landed and discarded fish are combined with the discard mortality rate and age-length data to compute recreational removals for each age-class (R_a) for use in the stock dynamics model.

8. The haddock minimum size limit changed from 18 to 21 inches in 2013; most (85%) of the sub-legal landings of haddock in 2013 were fish that were between 18 and 21 inches in length. Non-compliance with possession limits is more difficult to assess and is not included in this model.

The model is calibrated by setting the number of choice occasions (T) in each wave so that the number of predicted trips matches the number of estimated MRIP trips taken in 2013. For the calibration, the initial stock conditions for cod and haddock were set to the median 2013 projected stock structures. Calibrating the model to 396,000 choice occasions resulted in a prediction of 212,301 trips, closely matching the 212,578 trips that MRIP estimated occurred in 2013. The model slightly underestimates cod landings, discard weight, and mortality and overestimates numbers of discarded cod (table 2). Closer examination of the 2013 catch-per-trip and catch-at-length data shows that discrepancy is due to anglers discarding legal-size fish despite not having reached the possession limit, a type of behavior that is not included in the behavioral model. The average weight of discarded cod predicted by the model is 1.27 lbs., approximately 20% lower than the average weight of cod that were actually discarded in 2013.

The total catch of haddock predicted by the model approximately matches the 2013 outcomes. The calibrated model overestimates discards and underestimates haddock landings. We believe this is due to abnormally high non-compliance with the federal minimum size limit. Because the haddock regulations changed dramatically between 2012 and 2013 (from an 18″ minimum in 2012 to a 21″ minimum in 2013), this non-compliance may simply have occurred because anglers were not well informed about the regulations and that non-compliance will revert to historical levels in the future. The average weight of landed haddock predicted by the model was approximately 18% lower than the average weight of haddock that were actually landed in 2013. The average weight of discarded haddock predicted by the model was approximately 10% higher than the average weight of haddock actually discarded in 2013.

POLICY SIMULATIONS

To examine the effects of alternative policies considered for 2014 on fishing mortality, angler welfare, and future stock levels, we conduct a Monte Carlo experiment. The population of starting stock structures for cod and haddock are taken directly from the output of the relevant stock

Table 2. Simulation Model Calibration Diagnostics

	Model	2013 Actual	Error (%)
Trips	212,850	212,578	
Cod catch (pounds)	1,929,821	1,977,698	2.4
Landed	1,190,597	1,226,862	3.0
Discarded	739,224	750,836	1.5
Cod catch (numbers)	868,267	781,005	–11.2
Landed	299,374	301,697	0.8
Discarded	568,893	479,308	–18.7
Cod mortality (pounds)	1,412,365	1,452,113	2.7
Haddock catch (pounds)	1,428,682	1,439,308	0.7
Landed	395,093	529,011	25.3
Discarded	1,033,589	910,297	–13.5
Haddock catch (numbers)	639,971	630,857	–1.4
Landed	122,666	135,194	9.3
Discarded	517,305	495,663	–4.4
Haddock mortality (pounds)	395,093	529,011	25.3

assessment model.[9] Two hundred starting stock structures for both cod and haddock are randomly selected from those populations. For each initial stock structure, the model is simulated for three years (2014–2016) with a constant set of regulations. We vary minimum size limits, possession limits, and closures of bi-monthly waves to fishing.[10] This allows us to gain some insight into the effects of policy changes in addition to understanding how much variability in effort, landings, discards, and angler welfare might be due to uncertainty in initial stock composition and recruitment.

We present the results of eight selected policies that were considered by NMFS for the 2014 fishing year to illustrate how changes in regulations affect the recreational fishery and stocks of fish. Violin plots, which overlay a density estimate on the median and interquartile range (Hintze and Nelson 1998), are used to describe the outcomes of seven selected policies considered for 2014, labeled A through H (figure 4). Policy A represents the fishing regulations that were in place in 2013: a 9 cod limit with a 19″ minimum size and unlimited haddock with an 18″ minimum size. We compute CV using policy A as the initial conditions.

Policy H is the actual policy implemented by NMFS in 2014: 9 cod and 3 haddock possession limit, 21″ minimum size for both species, and closures of wave 5 for cod and waves 2 and 5 for haddock. Policies B through H include sets of measures that illustrate how changes in individual regulations affect the recreational fishery. For example, comparing policies A and F illustrates the effects of changes in possession limits holding the size limits constant, while comparing policies A, C, and D illustrate the effects of changing minimum sizes while holding the possession limits constant. We focus interpretation on both the median and the distribution of outcomes.

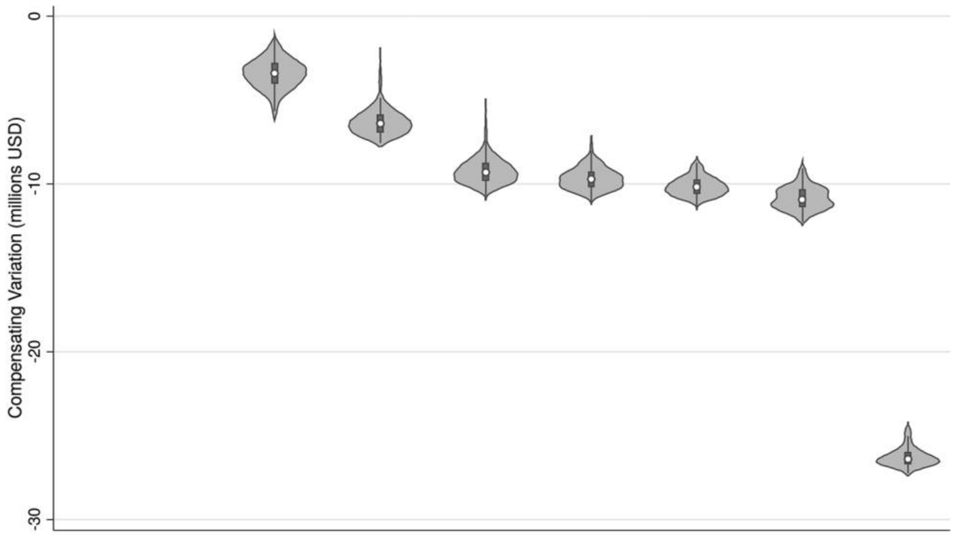
We first examine metrics that are most relevant to policy makers: angler welfare and recreational mortality. CV for policies B through H are all negative, indicating that recreational anglers are made worse off relative to the status-quo recreational fisheries policy. Furthermore, policy H (the actual policy implemented in 2014) results in the largest welfare losses (figure 4). To compute CV when waves are closed (policy H), we assume anglers elect not to take a saltwater fishing trip.[11] Similar patterns for both recreational cod mortality and recreational haddock mortality are evident, although there is substantially greater overlap in the distributions of these outcomes (figures 5a and b). In both plots, the 2014 recreational sub-ACLs are overlaid with a dashed line. Median mortality is below both recreational limits for only policy H, the actual policy enacted in 2014. Median cod removals range from 1.34M lbs. (policy A) to 874,000 lbs. (policy H). Median haddock removals range from 948,000 lbs. (policy A) to 167,000 lbs. (policy H). From these sets of graphs, we infer that meeting the low haddock sub-ACL is particularly costly for recreational anglers in terms of foregone welfare.

While the evaluated fisheries policies can have relatively large impacts on both anglers and recreational fishing mortality, they have minimal, if any, impact on the stock of either fish at the end of the three-year time horizon. Figures 5c and d show that predicted biomass of both species

9. Interview with P. Nitschke, NOAA Fisheries, Northeast Fisheries Science Center. October, 2014.

10. Due to data limitations, it is assumed that anglers are unable to reallocate cod and haddock fishing trips in 2014 in response to bi-monthly wave closures. Although some level of trip sorting would likely occur in response to a bi-monthly closure, we believe the extent of inter-temporal trip substitution would be low given changes in availability of cod and haddock by season, angler preferences, and angler time constraints.

11. When we allow anglers to take a saltwater fishing trip, but encounter neither cod nor haddock, median CV for policy H is approximately $-15.7M in the first year.



	A	B	C	D	E	F	G	H
Cod Bag	9	3	9	9	9	9	3	9
Haddock Bag	-	5	-	-	5	3	5	3
Cod Minimum	19	18	19	21	21	21	21	21
Haddock Minimum	18	18	21	21	21	21	21	21
Cod Closed								5
Haddock Closed								2,5

Figure 4. Aggregate Angler CV in 2014 Evaluated Over Seven Alternative Fishing Policies
Note: Policy A is used as the baseline policy.

at the end of year 3 are not sensitive to the seven alternative policies. There are two causes for this. First, the stock projection model contains a minimal stock-recruitment relationship; recruitment for haddock is purely stochastic, and cod recruitment depends on stock biomass only when SSB is extremely low. Reductions in harvest increase biomass only by allowing more fish to survive. If there was a positive relationship between stock and recruitment, reductions in harvest would also lead to higher levels of recruitment in future years. Second, recreational mortality of cod and haddock under all policies is low relative to both biomass and natural mortality for each species. For reference, the median biomass for cod and haddock used to initialize the simulations was 36 and 5.7 million lbs., respectively. $M = 0.2$ implies that in the absence of commercial and recreational fishing, 6.5 million lbs. of cod and 1.7 million lbs. of haddock die in the first year due to natural mortality. If stock levels were lower or recreational removals were higher, it is quite likely that alternative recreational regulations would lead to measureable changes in future biomass. While we simulate for only three years, it is reasonable to believe that all of these recreational policies would produce similar rebuilding times for cod.

We can examine more general effects of size and possession limits by comparing some of the policies. However, the effects are conditional on angler preferences and the current stock structures. It is not surprising that low minimum sizes lead to lower discards (figures 5e and f). Interestingly, combining low minimums with low possession limits (policy B) results in less variation in the range of outcomes for both angler welfare and fish removals compared to policies with higher possession and size limits (policies C and D). This is because anglers reach their possession limits relatively quickly and stop encountering cod and haddock when the possession limits

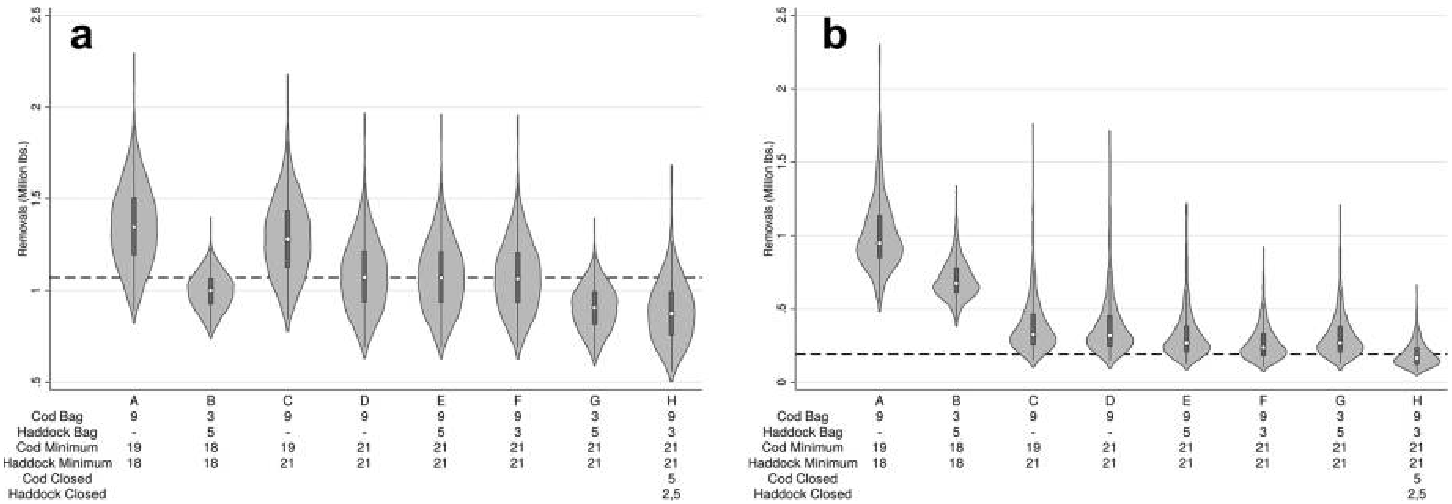


Figure 5. Plots of Model Outputs under Alternative Fisheries Policies (a) Cod Removals in 2014, (b) Haddock Removals in 2014, (c) Cod SSB on May 1, 2017, (d) Haddock SSB on May 1, 2017, (e) Cod Discards in 2014, and (f) Haddock Discards in 2014

Note: Recreational ACLs for cod and haddock are represented with dashed in lines in (a) and (b). While haddock SSB in sub-figure (d) appears to be negative, this is a statistical artifact of the kernel density estimator: haddock SSB is always positive, although there are outcomes that result in very low estimimates of biomass.

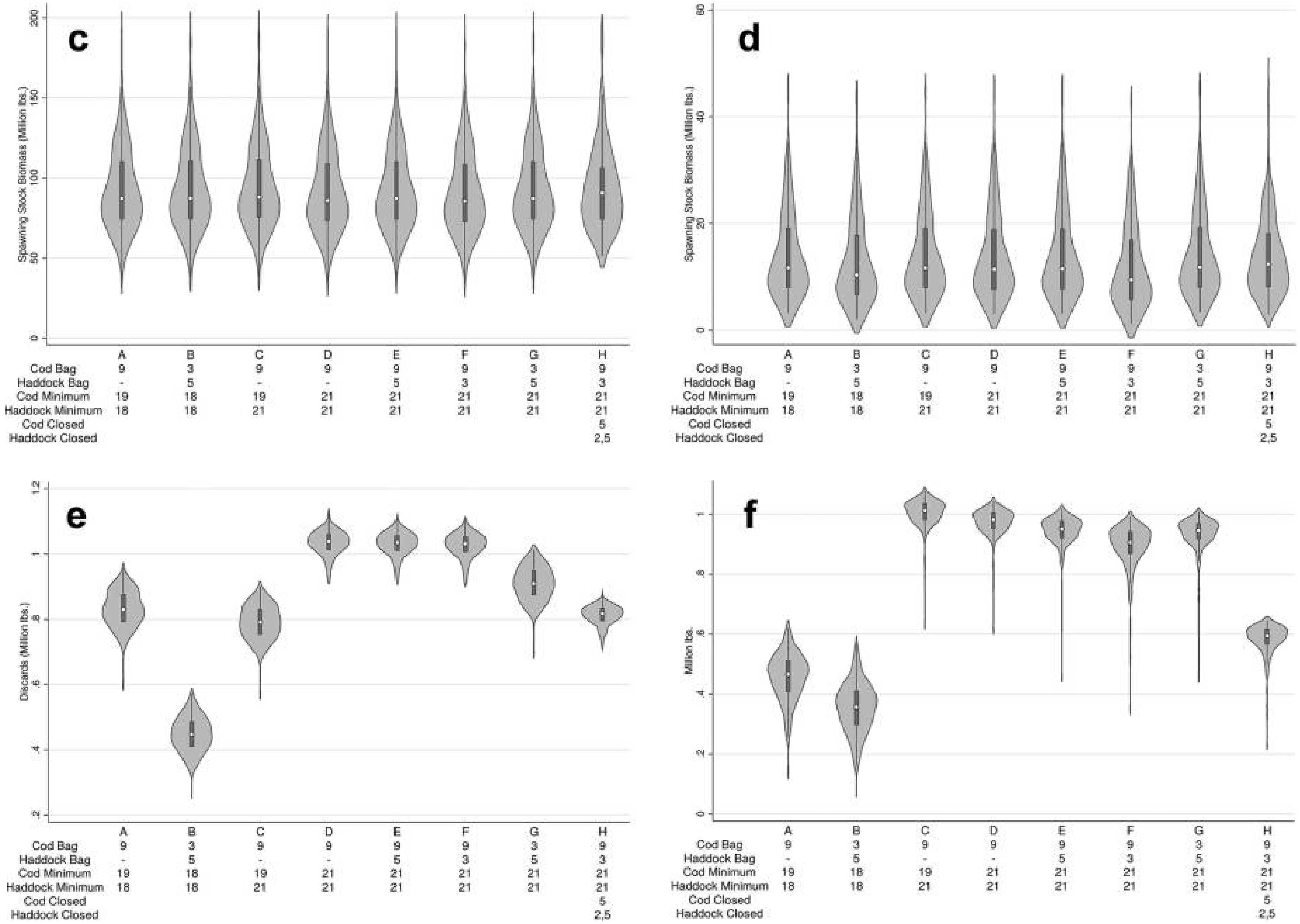


Figure 5 (*Continued*)

are met. Angler welfare levels are relatively high despite low removals of cod; anglers are able to retain small fish and have higher values on retaining these first few fish.

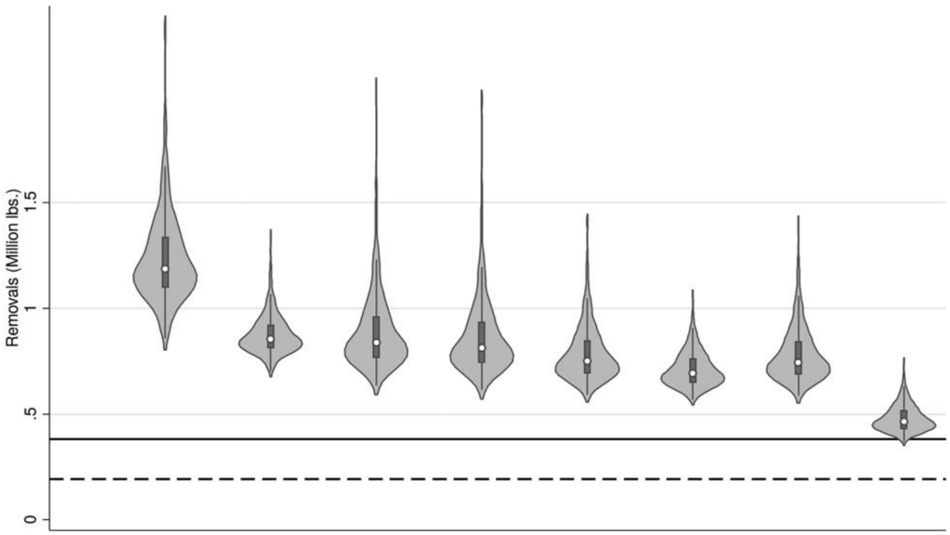
Changes in the regulations for one species have minimal impacts on removals of the other species. For example, the policy simulation results showed that increasing the haddock size limit from 18″ to 21″ (policy A to C) causes a dramatic decrease in the level of haddock removals, but produces only a small decrease of cod removals. Similarly, increasing the cod minimum size from 19″ to 21″ (policy C to D) has almost no effect on haddock removals and changes in the possession limits for cod (policy E to G) does not affect the level of haddock removals.

Comparing policy B to policy G shows that simultaneously increasing both minimum sizes while maintaining low possession limits has large impacts on haddock and cod removals. Increasing the size limits from 18″ to 21″ for both species results in a 7.5% reduction in median cod removals and a 60% reduction in median haddock removals. For cod, this is driven by a large decrease in landed cod that is partially offset by an increase in discarded fish, of which 30% are assumed to die. Haddock removals fall drastically because only a small fraction of the stock is 21″ or larger; the vast majority of haddock would be sub-legal, and therefore discarded, under policy C. Shifting from an unlimited haddock possession limit to a 5 fish limit has minimal impacts on haddock removals (policies D and G) at a 21″ minimum because there are so few legal-size fish. The closure of certain waves to fishing (policy H) reduces fishing mortality substantially compared to the identical set of regulations which allows fishing in those waves (policy F) by removing large amounts of fishing effort.

SOME SENSITIVITY ANALYSIS ABOUT DISCARD MORTALITY

When minimum size limits are high, the possession limits are not particularly restrictive; furthermore, these size limits have the potential to generate large amounts of discards. Increases in the minimum size produce lower landings and removals through increases in discarded fish. This may be a reasonable strategy for reducing haddock mortality if the discard mortality rate is low. However, discard mortality in recreational fisheries is not well understood and policies that rely on high survival of discarded fish to achieve conservation objectives may not achieve those goals if the discard mortality rate is revised to a higher level. That precise change occurred in the summer of 2014, when a new stock assessment for haddock included major changes in both recreational discard mortality and biomass estimates (NEFSC 2014). The haddock discard mortality rate was revised from 0 to 50%. The estimate of 2013 haddock SSB was revised to 9.14 million lbs., an increase of over 250% from the operational update. The resulting higher stock level allowed NMFS to double the haddock recreational ACL to approximately 381 thousand lbs. during the 2014 fishing year.

While the new haddock assessment did not suggest a substantially different stock dynamics model, new data indicated atypically strong year-classes spawned in 2010 and 2012. These new data, of course, would not have been available during the previous assessment or subsequent operational assessment. Therefore, it is not particularly surprising that the new stock assessment produced an estimate of haddock biomass that was quite different from the median projection of the operational update. Figure 6 illustrates how this new stock assessment changed the scientific understanding of haddock by plotting the “old” length structure of haddock (as projected by the 2012 haddock operational assessment) and “new” length structure (as estimated by the 2014 haddock stock assessment). The large 2010 and 2012 age-classes revealed in the 2014 assessment show up as peaks in the “new” length structure at approximately 9 and 16 inches.



	A	B	C	D	E	F	G	H
Cod Bag	9	3	9	9	9	9	3	9
Haddock Bag	-	5	-	-	5	3	5	3
Cod Minimum	19	18	19	21	21	21	21	21
Haddock Minimum	18	18	21	21	21	21	21	21
Cod Closed								5
Haddock Closed								2,5

Figure 6. Haddock Removals in 2014 Assuming a 50% Discard Mortality Rate

Note: All other model parameters are unchanged. Dotted line represents the initial recreational ACL of 192,000 lbs. Solid line represents the updated recreational ACL of 381,000 lbs. based on the 2014 haddock stock assessment (NEFSC 2014).

In order to examine the effects of the change in the discard mortality rate, we repeat our simulations incorporating only the new discard mortality rate for haddock. While the catch, landings, and discards are essentially unchanged in the first year, estimated haddock removals change quite dramatically. We find that none of the eight policies would have resulted in recreational haddock removals below either the old or new catch limits with the revised discard mortality rate (figure 7). If policymakers had known that the recreational discard mortality rate was 50% instead of 0% for haddock, a far different set of regulations would have been warranted. This simple sensitivity analysis incorporates only the new scientific information about the discard mortality rate and not the new age composition data.

DISCUSSION AND CONCLUSIONS

Under the MSFCMA, NMFS is required to prevent overfishing and rebuild depleted stocks of fish using "best available science" (MSFCMA 2007). This model improves the science of fisheries management by combining a utility theoretic model of angler participation with an age-structured population dynamics models for two stocks of fish. In 2014, strict recreational measures with large negative effects on angler welfare were enacted to meet these sub-ACLs. Unfortunately, we find minimal conservation benefits in the medium term: projected biomass in 2017 is not sensitive to the set of policies evaluated. We hope this particular finding is unique to this fishery and represents the exception, rather than the rule, in recreational fisheries management.

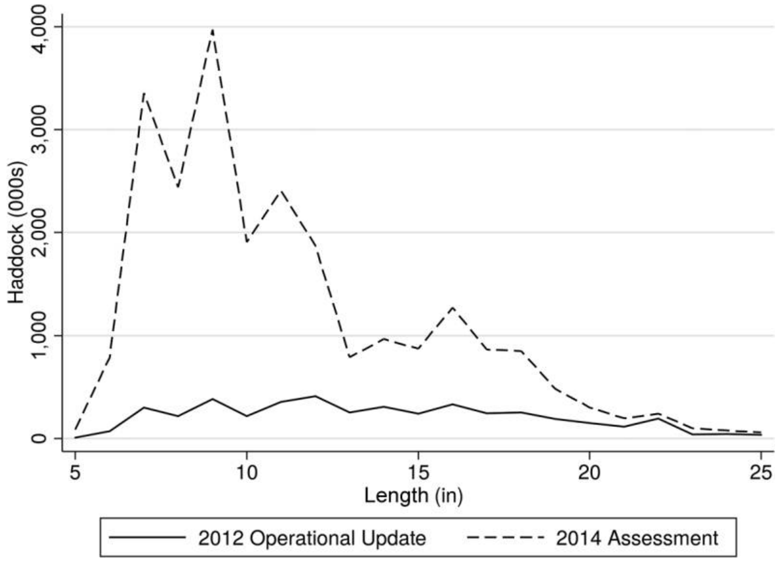


Figure 7. Haddock Length Structures in 2013 Corresponding to the 2012 Operational Assessment (solid) and 2014 Stock Assessment (dashed)

Note: The 2014 stock assessment resulted in a large change in the estimated biomass of haddock mainly due to the large 2010 and 2012 year classes.

Managing overfished groundfish stocks in New England has been challenging. In 2004, NMFS initiated rebuilding plans for overfished groundfish species, including GoM cod and haddock (NEFMC 2003). The MSFCMA mandates rebuilding overfished stocks to levels that can produce maximum sustainable yield, and NMFS currently requires rebuilding plans to have a 50% probability of success within 10 years, with exceptions for slowly growing stocks or needs of fishing communities. A 10-year rebuilding strategy was expected to produce minimal economic losses relative to a plan that rebuilt stocks quicker and the NEFMC selected a 10-year timeline to rebuild (NEFMC 2003). While the GoM haddock stock recovered relatively quickly (NEFSC 2008), cod did not recover, and a second rebuilding plan was initiated in 2014 (79 *Federal Register* 22421–49 [NOAA 2014b]). GoM cod continues to be difficult to manage; NMFS's 2015 Status of Stocks report to Congress notes that GoM cod is overfished, overfishing is occurring, and biomass is not increasing (NMFS 2016).

In our policy analysis, we have taken the sub-ACL for the recreational fleet as exogenous. In addition to the mandate to rebuild depleted stocks, the fishery management plan allocates one-third of the GoM cod ACL to the recreational sector. The costs of reductions in recreational fishing removals depend critically on regulations that produce those levels of fishing mortality (Abbott 2014; Holzer and McConnell 2014). Therefore, determining the optimal allocation across these two sectors is quite difficult; however, this model does suggest a way to examine this issue.

There is certainly room for improvement in many parts of the bioeconomic model. The behavioral model allows decreases in the quality of saltwater fishing to decrease recreational fishing effort and accompanying fishing mortality. In reality, anglers may respond to these decreases by adjusting targeting behavior, perhaps fishing for less desirable bottomfish like pollock or hake. If those alternative species are caught jointly with cod or haddock, our simulation model is likely to underestimate recreational removals of cod or haddock.

Furthermore, our simulation model assumes that anglers cannot reallocate trips across waves. A comparison of Policies F and H reveals that much of the decrease in removals is due to the closure of fishing for parts of the year. To the extent that anglers are able to reallocate trips, our simulation model will underestimate both fishing effort and removals. Research examining recreational angler preferences and substitution possibilities could improve model performance.

The integrated simulation model assumes that changes in stock levels do not impact the maximum numbers of fish encountered on a trip. This assumption is due to current data limitations; we are not able to specify a stock-catch relationship. Richardson, Palmer, and Smith (2014) show that both cod and commercial fishermen targeting cod aggregated into a relatively small area as a result of high prey abundances. These biological aggregations, along with optimizing behavior by fishermen, can lead to catch-per-unit-effort that is relatively insensitive to overall biomass, an effect known as "hyperstability" in the fisheries literature (Hilborn and Walters 1992; Harley, Myers, and Dunn 2001). Given these biological phenomena, the lack of a stock-catch relationship may be reasonable.

The integrated model also assumes that recreational effort within a wave is homogenous; the numbers and lengths of fish that are caught in different areas or by different modes are all drawn from the same wave-level distributions. Again, this assumption is due to data limitations unique to this particular fishery. With finer-scale data, it would be possible to incorporate angler heterogeneity at these levels. The numbers and lengths of catch of each species on a trip are both drawn independently. This may or may not be a reasonable assumption. For example, if fish aggregate by size then the lengths of fish caught on a trip are likely to be positively correlated. If cod and haddock are co-located in the ocean, then the number of cod caught on a trip is likely to be positively correlated with the number of haddock caught on that trip. Human behavior, such as angler skill or targeting, could also produce positive or negative correlations between numbers and length within and across species.

The variability in future biomass levels and the sensitivity of recreational removals to the discard mortality rate are two particularly striking features of our simulation results. The variability in future biomass for a given fishery policy is driven by the way recruitment for both stocks are currently modeled. Recruitment of age-1 fish is nearly independent of stock biomass and quite variable. This leads to fairly large variation in projected biomass and long upper tails just a few years in the future. While some natural variation in recruitment is irreducible, increased understanding of the stock-recruitment relationship should lead to better projections of biomass in the future. Similarly, the results of the integrated simulation model are quite sensitive to the discard mortality rate, and this particular parameter is not well understood.

In general, recreational fisheries management is complicated by limited availability of timely scientific information, abrupt changes in that information as irreducible uncertainty is resolved, the need to involve stakeholders, and procedural requirements associated with changing fishing regulations. Hanna (1995) notes that a slow timeline, information flow, good resource conditions, and incremental change encourage user participation in the fishery management process, and this can improve fishery management performance. Management of cod and haddock continues to be quite contentious (Hennessey and Healey 2000; Brodziak et al. 2008) and few, if any, of the characteristics identified by Hanna (1995) are present. In the Northeast US, NMFS works with the NEFMC to manage fisheries. NEFMC convenes a stakeholder group, the Recreational Advisory Panel (RAP), which provides advice and input on recreational policy. The ideal process for implementing or changing a recreational fishing regulation involves development of a feasible set of alternative policies in partnership with the RAP, a selection of a preferred policy from that feasible set by NEFMC, analysis of the economic and environmental effects of those policies, and a public comment period and response on the proposed rules prior to NMFS enacting federal fisheries regulations. In the recent past, the actual process used to set recreational regulations has been far from ideal and has allowed minimal opportunity for substantive participation by the RAP or the NEFMC.

The recent experience of setting recreational regulations in 2014, particularly for haddock, illustrates many of the difficulties of the fisheries management process. Information required to simply estimate recreational mortality are not available until the end of December, leaving four months for fishery managers to analyze, select, and implement recreational regulations before the beginning of the fishing year in May.[12] This compressed schedule limits the ability of stakeholders to share knowledge of stock conditions and provide input into the types of regulations that would be preferred. By 2014, managers had minimal information about the numbers of zero to four year-old haddock in the water because the 2012 operational assessment included data through 2010, and abundance estimates of age-0 fish are quite imprecise (NEFSC 2012). Three and four year-old fish are regularly encountered by the recreational fishery (see figures 1b and 2b). Because recreational policies depend heavily on size and possession limits to meet conservation goals, information about the age- or size-distribution is essential to fisheries management, but this information was quite out of date by 2014. In early 2014, the RAP indicated that anglers were encountering large amounts of small haddock, foreshadowing the discovery of a larger-than-expected 2010 year class. With a large cohort of small haddock, a 21″ minimum size limit would produce a far larger amount of discards than previously expected; similarly, a very low minimum size limit would result in a far larger amount of landings than otherwise expected. However, there was neither institutional flexibility nor time available to incorporate the RAP's information into the simulation model.

The RAP's on-the-water knowledge was confirmed by the 2014 haddock stock assessment, which indicated strong year-classes spawned in both 2010 and 2012 (NEFSC 2014). While the new haddock assessment did not suggest a substantially different stock dynamics model, biomass estimates were revised upwards substantially. The large 2010 and 2012 year-classes discovered in the new assessment show up as peaks in the "new" length structure at approximately 9 and 16 inches (figure 7). The estimate of biomass, and consequently the recreational ACL, increased dramatically. However, the increase in the haddock discard mortality rate, combined with frequent discarding of abundant small haddock (required by the 21″ minimum size limit), resulted in haddock removals well above the revised recreational ACLs.

These institutional shortcomings undermine effective fisheries management by reducing angler perceptions about the legitimacy and fairness of fishing regulations. Eventually, this can lead to lower levels of angler compliance with fishing regulations (Sutinen and Kuperan 1999; Hatcher et al. 2000). The recreational component of this fishery is best characterized as open-access with minimal monitoring. Fostering compliance with the primary regulations used to manage fishing mortality through good institutions is essential to effective fisheries management. Despite the shortcomings of the model and the institutional framework, use of this simulation model in the fishery management process represents a substantial step forward in the science of fisher-

12. While this may seem like enough time, the Administrative Procedure Act mandates, with limited exceptions, a public comment period (typically 30 days) and additional 30-day notice before a rule becomes effective.

ies management. Regulatory decisions that are based on empirically estimated functional relationships between angler participation, stock levels, and management measures should better meet the demands of both managers and recreational fishermen.

REFERENCES

Aas, O., W. Haider, and L. Hunt. 2000. "Angler Responses to Potential Harvest Regulations in a Norwegian Sport Fishery: A Conjoint-Based Choice Modeling Approach." *North American Journal of Fisheries Management* 20(4):940–50.

Abbott, J. K. 2014. "Fighting Over a Red Herring: The Role of Economics in Recreational-Commercial Allocation Disputes." *Marine Resource Economics* 30(1):1–20.

Abbott, J. K., and E. P. Fenichel. 2013. "Anticipating Adaptation: A Mechanistic Approach For Linking Policy and Stock Status to Recreational Angler Behavior." *Canadian Journal of Fisheries and Aquatic Sciences* 70(8):1190–208.

Anderson, L. G. 1993. "Toward a Complete Economic Theory of the Utilization and Management of Recreational Fisheries." *Journal of Environmental Economics and Management* 24(3):272–95.

Beard, T. D., S. P. Cox, and S. R. Carpenter. 2003. "Impacts of Daily Bag Limit Reductions on Angler Effort in Wisconsin Walleye Lakes." *North American Journal of Fisheries Management* 23(4):1283–93.

Brodziak, J., S. X. Cadrin, C. M. Legault, and S. A. Murawski. 2008. "Goals and Strategies for Rebuilding New England Groundfish Stocks." *Fisheries Research* 94(3):355–66.

Brodziak, J., P. Rago, and R. Conser. 1998. "A General Approach for Making Short-Term Stochastic Projections from an Age-Structured Fisheries Assessment Model." In *Proceedings of the International Symposium on Fishery Stock Assessment Models for the 21st Century*, 933–1012. Alaska Sea Grant College Program. Fairbanks, AK: University of Alaska Fairbanks.

Carson, R., M. Hanemann, and D. Steinberg. 1990. "A Discrete Choice Contingent Valuation Estimate of the Value of Kenai King Salmon." *Journal of Behavioral Economics* 19(1):53–68.

Carter, D. W., and C. Liese. 2012. "The Economic Value of Catching and Keeping or Releasing Saltwater Sport Fish in the Southeast USA." *North American Journal of Fisheries Management* 32(4): 613–25.

Cleveland, W. S. 1979. "Robust Locally Weighted Regression and Smoothing Scatterplots." *Journal of the American Statistical Association* 74(368):829–36.

Daw, T. M. 2008. "Spatial Distribution of Effort by Artisanal Fishers: Exploring Economic Factors Affecting the Lobster Fisheries of the Corn Islands, Nicaragua." *Fisheries Research* 90(1–3):17–25.

Dillman, D. A. 2000. *Mail and Internet Surveys: The Tailored Design Method*, 2nd ed. New York: Wiley.

Fenichel, E. P., J. K. Abbott, and B. Huang. 2013. "Modelling Angler Behavior as a Part of the Management System: Synthesizing a Multi-Disciplinary Literature." *Fish and Fisheries* 14(2):137–57.

Gentner, B., and S. Steinback. 2008. "The Economic Contribution of Marine Angler Expenditures in the United States, 2006." US Department of Commerce, NOAA Technical Memorandum NMFS–F/SPO–94, Woods Hole, MA.

Gillig, D., R. Woodward, T. Ozuna, Jr., and W. L. Griffin. 2003. "Joint Estimation of Revealed and Stated Preference Data: An Application to Recreational Red Snapper Valuation." *Agricultural and Resource Economics Review* 32(2):209–21.

GMFMC (Gulf of Mexico Fishery Management Council). 2013. "Red Snapper 2013 Quota Increase and Supplemental Recreational Season. Framework Action to the Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico." http://www.gulfcouncil.org/docs/amendments/Final%20Red%20Snapper%20Framework%20Action%20Set%202013%20Quotas%2008–01–13.pdf.

Haab, T. C., R. L. Hicks, and J. C. Whitehead. 2005. "The Economic Value of Marine Recreational Fishing: Analysis of the MRFSS 1998 Pacific Add-on." Paper presented at the annual meeting of the American Fisheries Society, September 11–15, Anchorage, AK.

Hanna, S. S. 1995. "User Participation and Fishery Management Performance within the Pacific Fishery Management Council." *Ocean & Coastal Management* 28(1–3):23–44.

Harley, S. J., R. A. Myers, and A. Dunn. 2001. "Is Catch-per-Unit-Effort Proportional to Abundance?" *Canadian Journal of Fisheries and Aquatic Sciences* 58(9):1760–72.

Hatcher, A., S. Jaffry, O. Thébaud, and E. Bennett. 2000. "Normative and Social Influences Affecting Compliance with Fishery Regulations." *Land Economics* 76(3):448–61.

Hennessey, T., and M. Healey. 2000. "Ludwig's Ratchet and the Collapse of New England Groundfish Stocks." *Coastal Management* 28(3):187–213.

Hicks, R. L., T. C. Haab, and D. Lipton. 2004. "Economic Benefits of Oyster Reef Restoration in the Chesapeake Bay." Final Report Prepared for the Chesapeake Bay Foundation, Williamsburg, VA.

Hilborn, R., and C. J. Walters. 1992. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. New York: Chapman and Hall.

Hintze, J. L., and R. D. Nelson. 1998. "Violin Plots: A Box Plot-Density Trace Synergism." *The American Statistician* 52(2):181–84.

Holland, D. S. 2000. "A Bioeconomic Model of Marine Sanctuaries on Georges Bank." *Canadian Journal of Fisheries and Aquatic Sciences* 57(6):1307–19.

Holzer, J., and K. McConnell. 2014. "Harvest Allocation without Property Rights." *Journal of the Association of Environmental and Resource Economists* 1(1):209–32.

Homans, F. R., and J. A. Ruliffson. 1999. "The Effects of Minimum Size Limits on Recreational Fishing." *Marine Resource Economics* 14(1):1–14.

Jarvis, S. L. 2011. "Stated Preference Methods and Models: Analyzing Recreational Angling in New England Groundfisheries." PhD diss., Department of Agricultural and Resource Economics, University of Maryland.

Kahui, V., and W. R. J. Alexander. 2008. "A Bioeconomic Analysis of Marine Reserves for Paua (Abalone) Management at Steward Island, New Zealand." *Environmental and Resource Economics* 40(3):339–67.

Kaoru, Y. 1995. "Measuring Marine Recreation Benefits of Water Quality Improvements by the Nested Random Utility Model." *Resource and Energy Economics* 17(2):119–36.

Lew, D., and D. Larson. 2012. "Economic Values for Saltwater Sport Fishing in Alaska: A Stated Preference Analysis." *North American Journal of Fisheries Management* 32(4):745–59.

Lipton, D., and R. L. Hicks. 2003. "The Cost of Stress: Low Dissolved Oxygen and Economic Benefits of Recreational Striped Bass Fishing in the Patuxent River." *Estuaries and Coasts* 26(2):310–15.

MAFMC (Mid-Atlantic Fishery Management Council). 2013. "Summer Flounder, Scup, and Black Sea Bass Recreational Specifications Black Sea Bass Catch Limits for 2013 and 2014." Supplemental Environmental Assessment, Dover, DE.

Massey, D. M., S. C. Newbold, and B. Gentner. 2006. "Valuing Water Quality Changes Using a Bioeconomic Model of a Coastal Recreational Fishery." *Journal of Environmental Economics and Management* 52(1):482–500.

McConnell, K., I. Strand, and L. Blake-Hedges. 1995. "Random Utility Models of Recreational Fishing: Catching Fish Using a Poisson Process." *Marine Resource Economics* 10(3):247–61.

McFadden, D., and K. Train. 2000. "Mixed MNL Models for Discrete Response." *Journal of Applied Econometrics* 15(5):447–70.

MSFCMA (Magnuson-Stevens Fishery Conservation and Management Reauthorization Act). 2007. Public Law No. 109–479.

NOAA (National Oceanic and Atmospheric Administration). 2014a. Magnuson-Stevens Fishery Conservation and Management Act Provisions; Fisheries of the Northeastern United States; Northeast Groundfish Fishery; Fishing Year 2014; Recreational Management Measures. *Federal Register* 79 no 77 (April 22, 2014): 22419–21. http://www.gpo.gov/fdsys/pkg/FR–2014–04–22/pdf/2014–09140.pdf.

———. 2014b. Magnuson-Stevens Fishery Conservation and Management Act Provisions; Fisheries of the Northeastern United States; Northeast Groundfish Fishery; Framework Adjustment 51. *Federal Register* 79 no 77 (April 22, 2014): 22421–49. https://www.gpo.gov/fdsys/pkg/FR–2014–04–22/pdf/2014–09135.pdf

NEFMC (New England Fishery Management Council). 2003. Amendment 13 to the Northeast Multispecies Fishery Management Plan. Newburyport, MA.

NEFSC (Northeast Fisheries Science Center). 2008. "Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3rd Groundfish Assessment Review Meeting (GARM III)." Northeast Fisheries Science Center Reference Document 08–15, US Department of Commerce, National Marine Fisheries Service, Woods Hole, MA.

———. 2012. "Assessment or Data Updates of 13 Northeast Groundfish Stocks through 2010." Northeast Fisheries Science Center Reference Document 12–06, US Department of Commerce, National Marine Fisheries Service, Woods Hole, MA.

———. 2013. "55th Northeast Regional Stock Assessment Workshop (55th SAW) Assessment Report." Northeast Fisheries Science Center Reference Document 13–11, US Department of Commerce, National Marine Fisheries Service, Woods Hole, MA.

———. 2014. "59th Northeast Regional Stock Assessment Workshop (59th SAW) Assessment Summary Report." Northeast Fisheries Science Center Reference Document 14–07, US Department of Commerce, National Marine Fisheries Service, Woods Hole, MA.

Newbold, S. C., and D. M. Massey. 2010. "Recreation Demand Estimation and Valuation in Spatially Connected Systems." *Resource and Energy Economics* 32(2):222–40.

NMFS (National Marine Fisheries Service). 2014. "Status of Stocks 2013: Annual Report on the Status of U.S. Fisheries." Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, MD.

———. 2016. "Status of Stocks 2015: Annual Report on the Status of U.S. Fisheries." Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, MD.

Oh, C. O., R. B. Ditton, B. Gentner, and R. Riechers. 2005. "A Stated Preference Choice Approach to Understanding Angler Preferences for Management Options." *Human Dimensions of Wildlife* 10(3): 173–86.

Post, J. R., C. Mushens, A. Paul, and M. Sullivan. 2003. "Assessment of Alternative Harvest Regulations for Sustaining Recreational Fisheries: Model Development and Application to Bull Trout." *North American Journal of Fisheries Management* 23(1):22–34.

Post, J. R., L. Persson, E. V. Parkinson, and T. V. Kooten. 2008. "Angler Numerical Response across Landscapes and the Collapse of Freshwater Fisheries." *Ecological Applications* 18(4):1038–49.

Richardson, D. E., M. C. Palmer, and B. E. Smith. 2014. "The Influence of Forage Fish Abundance on the Aggregation of Gulf of Maine Atlantic Cod (*Gadus morhua*) and their Catchability in the Fishery." *Canadian Journal of Fisheries and Aquatic Sciences* 71(9):1349–62.

Ricker, W. E. 1975. "Computation and Interpretation of Biological Statistics of Fish Populations." Bulletin 191 of the Fisheries Research Board of Canada. Department of the Environment, Fisheries, and Marine Service, Ottawa, ON.

Schaefer, M. B. 1954. "Some Aspects of the Dynamics of Populations Important to the Management of the Commercial Marine Fisheries." *Inter-American Tropical Tuna Commission Bulletin* 1(2):23–56.

Schuhmann, P. W. 1998. "Deriving Species-Specific Benefits Measures for Expected Catch Improvements in a Random Utility Framework." *Marine Resource Economics* 13(1):1–21.

Shideler, G. S., D. W. Carter, C. Liese, and J. E. Serafy. 2015. "Lifting the Goliath Grouper Harvest Ban: Angler Perspectives and Willingness to Pay." *Fisheries Research* 161(1):156–65.

Smith, M. D., J. Zhang, and F. C. Coleman. 2008. "Econometric Modeling of Fisheries with Complex Life Histories: Avoiding Biological Management Failures." *Journal of Environmental Economics and Management* 55(3):265–80.

Stoll, J. R., and R. B. Ditton. 2006. "Understanding Anglers' Willingness to Pay Under Alternative Management Regimes." *Human Dimensions of Wildlife* 11(1):27–42.

Sutinen, J. G., and K. Kuperan. 1999. "A Socio-economic Theory of Regulatory Compliance." *International Journal of Social Economics.* 26(1/2/3):174–93.

Train, K. E. 2003. *Discrete Choice Methods with Simulation*. New York: Cambridge University Press.

Whitehead, J. C., C. F. Dumas, C. E. Landry, and J. Herstine. 2011. "Valuing Bag Limits in the North Carolina Charter Boat Fishery with Combined Revealed and Stated Preference Data." *Marine Resource Economics* 26(3):233–41.

Whitehead, J. C., and T. C. Haab. 1999. "Southeast Marine Recreational Fishery Statistics Survey: Distance and Catch Based Choice Sets." *Marine Resource Economics* 14(4):283–98.

Woodward R. T., and W. L. Griffin. 2003. "Size and Bag Limits in Recreational Fisheries: Theoretical and Empirical Analysis." *Marine Resource Economics*. 18(3):239–62.