Estimating the Economic Impact of Climate Change on the Freshwater Sportsfisheries of the Northeastern U.S.

Linwood H. Pendleton and Robert Mendelsohn

ABSTRACT. *This study links models of global climate circulation, ecology, and economic valuation (hedonic travel cost and random utility models) to value the impact of global warming on freshwater sportfishing in the northeastern United States. An origin-specific linear random utility model (RUM) is introduced. The results of the RUM are shown to be comparable to those of a hedonic travel cost model. A doubling of atmospheric carbon dioxide is predicted to generate between a $4.6 million loss and a $20.5 million net benefit for the Northeast, depending on the climate scenario.* (JEL Q26)

I. INTRODUCTION

This study links global climate models (GCM) with ecological models of fish catch rates (yield) to determine the impact of a doubling of atmospheric CO_2 on the quality of freshwater fishing in the northeastern United States. Many freshwater fish species are known to be sensitive to changes in atmospheric temperature, the amount of precipitation, and the acidity of precipitation (Minns and Moore 1992; Meisner 1990; Regier and Meisner 1990; and Englin et al. 1991). The range and abundance of cold-water fish species, such as rainbow trout, could be diminished if global warming becomes a reality, while the range and abundance of warm-water fish species may actually increase. Climate-linked changes in fish populations could result in economic changes in the welfare of anglers. The degree to which anglers are harmed or helped by climate change depends on the net ecological effects of climate change. Losses in cold-water species could be offset by gains in the abundance and distribution of favored warm-water species.

In what follows, we offer an attempt to measure the combined impacts of climate change on the welfare of freshwater anglers in the northeastern United States. We start by modeling the ecological impacts of climate change on freshwater fish catch. The ecological impacts that would follow from climate change then are valued using two revealed preference methods: the hedonic travel cost method and an "origin-specific" linear random utility model (RUM). The "origin-specific" RUM model permits the implicit modeling of origin-specific angler preferences. These origin-specific preferences cannot be accounted for, implicitly or otherwise, by the standard application of the RUM across all origins. Our results indicate that valuations of marginal changes in fish populations are approximately similar using the origin-specific RUM and the hedonic travel cost (HTC) methods. Finally, this paper demonstrates that climate change will alter fish populations and, in turn, will affect angler welfare.

II. METHODOLOGY

The Modeling Framework

This study combines global circulation models, ecological models of fish catch, and economic models to estimate the impacts of a doubling of CO_2 on freshwater sportfishing in the northeastern United States. A flow diagram of the modeling framework is given in Figure 1.

This study estimates the ecological and economic models based on actual data. Williams et al. (1996) use the GCM models of the Goddard Institute of Space Science (GISS) and Oregon State University (OSU)

The authors are, respectively, assistant professor of economics at the University of Southern California and Weyerhaeuser Davis Professor at the Yale University School of Forestry and Environmental Studies. Support for this research was provided by Department of Energy grant #DE-FG02-95ER62115, a Joseph L. Fisher Fellowship from Resources for the Future, Yale University, and the Woods Hole Oceanographic Institution's Marine Policy Center. Special acknowledgment is given to Jeff Englin for his help interpreting the data and Theodore Schwartz for his able research assistance.

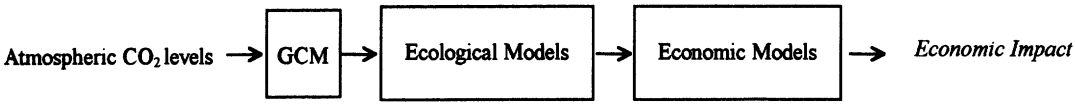

FIGURE 1
THE MODELING FRAMEWORK

to predict climate changes on a county-level basis. The ecological models that follow use predicted county-level climate changes, from Williams et al. (1996), to predict changes in fish catch rates which are then valued by the economic models. The details of each of the steps in the overall model follow.

The Ecological Models

Ecological models that relate climatic variables to fish growth and abundance show that both temperature and precipitation often have marked effects on many species of freshwater fish (Minns and Moore 1992; Meisner 1990; Regier and Meisner 1990). Climate can affect the abundance of fish through the impacts of air temperature and precipitation on aquatic microclimates in streams that feed lakes and the aquatic environment of the actual lakes.[1] In our ecological models we do not explicitly model the links between climate and streams or lakes. Instead our ecological models use as independent variables data on seasonal air temperature and precipitation. The way in which air temperature and precipitation affect the relevant aquatic environments is left unconstrained. In point of fact, the stream environment is directly affected by climate, while the effects of climate on the lake environment may be moderated by physical characteristics including depth and stratification. There exists a precedent in the literature for using air temperature as a measure of climate for fisheries. Meisner et al. (1987) cite numerous studies of climatic influences on lakes in which mean annual air temperature was used to proxy water temperature. Other studies by Minns and Moore (1992), Meisner (1990), Regier and Meisner (1990), McCauley and Kilgour (1990), and Shuter and Post (1990) also model fish populations using air temperature. The ecological models presented below incorporate climatic parameters, physical characteristics of lakes, and other relevant biological and chemical lake parameters to estimate models of fish yield.

From an ecological perspective, we would like to model fish stock directly. Unfortunately, data are not available on the abundance of fish within the lakes of our study area. Like other authors (Minns and Moore 1992), we model the impacts of climate change on a measure of yield (we use catch per unit effort) rather than on stock. As an anonymous reviewer points out, the relationship between yield and stock usually is given by a yield function of the form $Y = qX^{\alpha}E^{\beta}$, where Y is yield, q is a measure of catchability, X is stock, and E is effort. When α and β are both equal to one, the catch per unit effort $(Y/E) = qX$ and so catch rate and stock vary proportionately. Climate could affect stock directly and might also affect catchability if fish stay deeper to avoid increased temperatures. By estimating the relationship between catch rate and climate, we avoid the need to estimate separately the impacts of climate on stock and catchability.

We explored a variety of model specifications, all linear in variables, to find the suite of morphometric, chemical, biological, and climatic variables that best explains fish catch rates (catch per unit effort, CPUE) for each species group. For each species, we begin with the basic model

$$\begin{aligned}\text{CPUE(species } i) = {} & \beta_1(\text{mean seasonal temperature}) \\ & + \beta_2(\text{mean seasonal precipitation}) \\ & + \beta_3(\text{physical or vegetative features}). \quad [1]\end{aligned}$$

[1] Thanks to an anonymous reviewer for pointing out the importance of streams.

Mean seasonal (April, July, October, January) temperature and precipitation data are available for each county in the study area (see Williams et al. 1996). Because seasonal temperatures tend to be highly correlated, we can use only one seasonal temperature in each ecological model. Studies by Minns and Moore (1992), Meisner (1990), and Regier and Meisner (1990) show that annual freshwater temperature extremes are important determinants of fish growth, survival, and subsequently abundance. The sensitivity of individual fish species to temperature and precipitation depends on the particular life history and physiology of that fish. For instance, warm-water fish are likely to be affected more by changes in cold water boundaries (temporal or geographic) while the opposite is true for cold-water fish. We begin the estimation of each model using mean July temperatures for fish considered to be cold-water fish and October and January temperatures for warm-water fish. (Other model specifications also include other seasonal temperatures.) Since pan fish, one of our taxa, is composed of both cold- and warm-water species, we tried model specifications that included all mean temperatures for January, April, July, and October. The specific temperature, precipitation, physical, and vegetative variables chosen for the final model specifications are those that yield models with the highest explanatory power based on the adjusted r-squared measure of goodness of fit. (The constant terms in the models are adjusted to account for the fact that the models were estimated originally in °F.) Table 1 summarizes the ecological models used to predict the CPUEs for rainbow trout, all trout other than rainbow trout, and pan fish.

Fish catch rates (CPUEs) under conditions of a doubling of carbon dioxide were predicted based on current baseline information on CPUEs from the NAPAP fishing surveys and predicted changes in CPUEs from the GCM and ecological models. County-specific changes in seasonal temperature and precipitation levels were derived from GISS and OSU predictions of climatic change (Williams, Shaw, and Mendelsohn 1996). The change in climatic variables enter directly into the CPUE models to determine the expected change in CPUE for each species (equation [2]):

$$\Delta \text{CPUE}_i = \gamma_i(\Delta \mathbf{V}), \tag{2}$$

where the subscript refers to fish species group i, γ_i is a vector of the coefficients on

TABLE 1

THE ESTIMATED ECOLOGICAL MODELS

Variable	Variable Description	Units	Coefficient	t-statistic
Catch Rate Model of Rainbow Trout				
CONSTANT	Constant term		6.2473	
LEAFY	Shore in leafy vegetation	%	0.0095	(4.1045)
July Temp.	Mean July temperature	°C	−0.3262	(−3.4538)
April Precip.	Mean April precipitation	Centimeters	2.8811	(3.8292)
October Precip.	Mean Oct. precipitation	Centimeters	−2.6919	(−3.6303)
		Observations = 32	$r^2 = 0.47$	
Catch Rate Model of All Trout Other Than Rainbow Trout				
CONSTANT	Constant term		0.5376	
Weediness	Measure of weeds in lake	1 to 5	−0.1463	(−3.6878)
Visibility	Mean visibility	Feet	0.0533	(3.8938)
SIO_2	Silicon dioxide	(mg/L)	0.1350	(4.5286)
STRAT	Lake stratification	1 to 3	−0.3030	(−2.4147)
October Temp.	Mean Oct. temperature	°C	0.0302	(3.0807)
		Observations = 32	$r^2 = 0.72$	
Catch Rate Model of Pan Fish				
CONSTANT	Constant term		0.2048	
MEADOW	Shore vegetation in meadow	%	0.0635	(2.2416)
April Temp.	Mean April temperature	°C	0.0115	(2.1993)
		Observations = 32	$r^2 = 0.14$	

the climatic variables from the ecological model specific to species i, and $\mathbf{V}$ is a vector of climatic parameters. We calculate a predicted catch rate, $CPUE_i^p$, that is the baseline $CPUE_i$ plus $\Delta CPUE_i$. Catch rates are set equal to zero in cases where $CPUE^p < 0$. A negative $CPUE_i^p$ simply means that species group i did not previously exist at a site or will be driven to local extinction under the predicted climatic conditions.

The Economic Models

This study uses both the random utility model (RUM) and the hedonic travel cost (HTC) model to value the economic impact of climate changes on recreational anglers. Both the RUM and HTC models have been well developed in the literature (for the RUM see McFadden 1978; Bockstael, Hanemann, and Kling 1987; Parsons and Kealy 1992; Parsons and Needleman 1992; Morey, Rowe, and Watson 1993; Hausman, Leonard, and McFadden 1995; and Karou, Smith, and Liu 1995; for the HTC see Brown and Mendelsohn 1984; Mendelsohn 1984; Smith and Karou 1987; Englin and Mendelsohn 1991; and Smith, Palmquist, and Jakus 1991). This study differs from previous studies in that we estimate separate linear HTC and RUM models for each origin.

Previous RUM studies of recreational fishing estimate a single (usually linear) utility function for anglers from all origins. When there exists a single market, it can be argued that a single linear utility function is a reasonable approximation of a small segment of a well-behaved utility function (i.e., concave and monotonically increasing)—especially when the changes in attributes to be considered are only marginal. Figure 2 shows how a linear functional form, U^{LA},

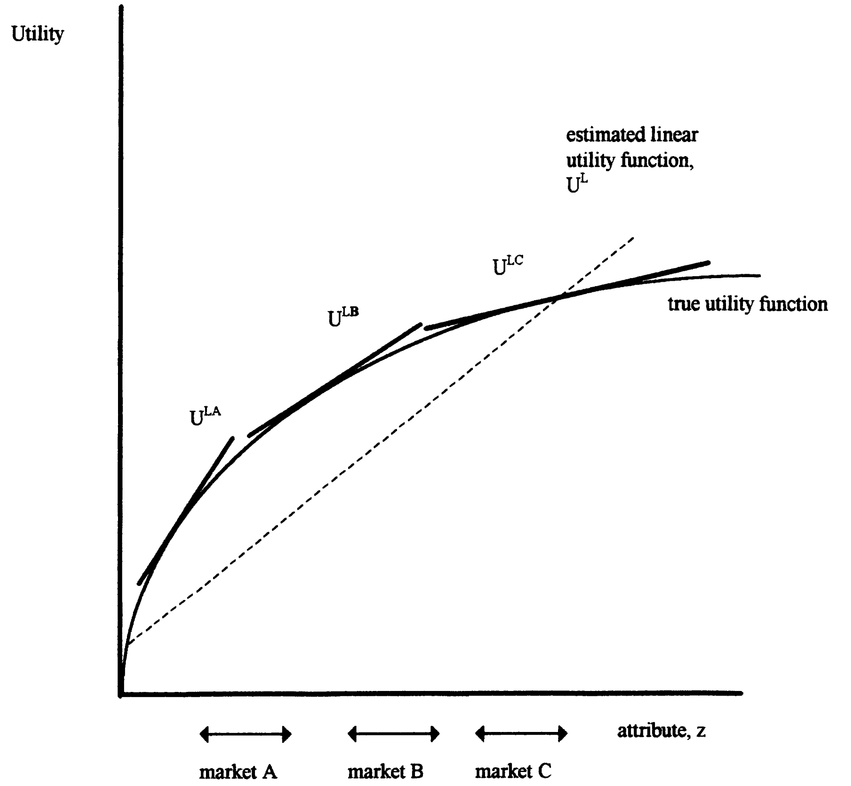

FIGURE 2
ESTIMATING UTILITY USING A LINEAR FUNCTIONAL FORM

might closely approximate marginal utility when it is estimated for a single market, A. When the utility function is estimated using data from multiple markets, each with different prices and different fixed supplies of attributes, a single linear utility function may be a bad approximation of the true utility function, especially if the true utility function is highly nonlinear. Figure 2 also demonstrates how a linear functional form, U^L, might fail to approximate even marginal utility when estimated for multiple markets (A, B, and C). In the case of multiple markets where levels of attributes vary considerably, a different linear utility could be calculated for different segments of the utility function (see Figure 2, curves U^{LA}, U^{LB}, and U^{LC}). In practice, these segments could be represented by different markets (see Figure 2, markets A, B, and C). In this study, each origin acts as a separate market. The mean levels of attributes experienced by anglers from each origin varies considerably.

Recreation demand models often deal with different origins, each with its own market. Therefore, an origin-specific linear functional form would appear to be an appropriate method for estimating random utility. Even though each market has a constant marginal utility for each characteristic, an origin-specific linear utility would permit decreasing marginal returns across all markets and also would allow for negative marginal values in those cases where attributes are available only in excess. An origin-specific linear utility approach also implicitly captures socioeconomic differences that may exist between different origins. These socioeconomic factors are not easily modeled using the traditional single utility RUM approach.

The estimation of the origin-specific HTC and RUM models is straightforward. The first-stage hedonic price functions (equation [3]) correspond directly to the estimation of the origin-specific marginal values of attributes (see Englin and Mendelsohn 1991 or Brown and Mendelsohn 1984). We estimate a separate hedonic price function $C(\mathbf{z})$ for each origin

$$C(\mathbf{z}) = \alpha + \beta\mathbf{z} + \varepsilon \qquad [3]$$

where $\mathbf{z}$ is the vector of mean CPUEs for each lake and the mean number of boat ramps for each lake as reported by anglers, $C(\mathbf{z})$ is the total cost of travel from the origin to the site, α is a constant, β is a vector of estimated hedonic (implicit) marginal prices, and ε is a random error variable.

The RUM estimates, for each of the origins separately, the linear conditional indirect utility function U

$$U = \beta\mathbf{z} = \lambda[Y - C(\mathbf{z})] + \mu, \qquad [4]$$

where Y is income, μ is a random variable, and the other variables are defined as before. In the RUM analysis, we use a multinomial logit estimation package (SST, Dubin and Rivers 1990) to estimate β and λ. In practice, Y cannot be included in the estimation using multinomial logit methods and the indirect utility function that is estimated is

$$v = \beta\mathbf{z} - \lambda[C(\mathbf{z})] + \mu. \qquad [5]$$

Following Englin et al. (1991), the estimated RUM models are non-nested. The basic principles of the non-nested multinomial logit are available throughout the literature. The method assumes that consumers maximize a random utility function that contains a logistically distributed error term.

The logit estimation of the RUM analysis requires that the model includes all destinations having a non-negative probability of being visited. When the choice set that includes all such destinations is prohibitively large, McFadden (1978, 75–96) showed that the model could be estimated using a limited set of destinations provided that these destinations were chosen randomly from the full set of destinations, all of which had a nonzero probability of being chosen. In this study, we define the choice set for any individual as those destinations that are visited by at least one person from that individual's origin. Sites that are not visited cannot be said, with certainty, to have a nonzero probability of being visited. The actual choice set differs for each origin. This definition of the choice set as only those sites currently visited is consistent with the theory of the RUM. Parsons and Kealy (1992) argue that the choice set should include all possible destinations within a given distance of the consumer. However, the method of Parsons and Kealy may lead to the wrongful inclusion of sites with a zero probability of being visited. The inclusion of sites with a zero probability of inclusion can lead to biased coefficient estimates (Parson and Kealy 1992).

Estimating Economic Welfare Change

The economic value of marginal changes in fish catch rates are calculated easily using the results from both the ecological and economic model estimations. The estimates of the marginal prices of catch rates are derived directly from the RUM and HTC models. In the RUM, the marginal price is given by: $MP(z_i) = \delta v/\delta z_i \div [-\delta v/\delta TC]$. In the HTC, the marginal price is given by: $MP(z_i) = \delta C(\mathbf{z})/\delta z_i$. The total value of marginal changes in fish catch rates for an angler that visits a given lake is given by equation [6]:

$$\text{total value of marginal change} = \sum \Delta z_i^* MP_i \quad [6]$$

where MP is marginal price and the subscript i references the fish species group. Calculation of the total value of marginal changes in fish catch rates assumes that changes in fish catch rate do not affect the marginal value of fish catch.

An exact measure for the value of non-marginal changes in fish catch rates also can be calculated using the RUM and HTC methods but to do so strains the extrapolative limits of the two models. RUM studies of fish catch often estimate the expected value of welfare change by the following formula

$$CV_{\text{RUM}} = \frac{1}{\lambda}\left\{\ln\left[\sum_J \exp\{v(\mathbf{z}_j^1)\}\right] - \ln\left[\sum_J \exp\{v(\mathbf{z}_j^0)\}\right]\right. \quad [7]$$

where CV is the exact welfare measure—the Hicksian compensating variation. The domain for the calculation of CV_{RUM} is all sites that have a nonzero probability of being visited. Of course, for CV to be an accurate measure of exact welfare change, the estimated (indirect) utility function, v, must exactly model the true utility of the angler. While RUM models that are linear in attributes may do a good job of estimating the value of marginal utility, it is unlikely that a single, linear in attributes model provides a good approximation of utility over a non-marginal range of attributes. Similarly, the results of the HTC estimation also can be used to derive consumer surplus measures and exact measures of welfare change for non-marginal changes in attributes. To develop HTC welfare measures for non-marginal changes in fish catch rates, demand functions must be estimated in which the demand for each fish species (in terms of catch rate) is a function of the hedonic prices of the fish catch rates. Unfortunately, the demand functions from the hedonic models often suffer from low explanatory power.

As long as we consider only small changes in each attribute, the marginal values estimated by the origin-specific RUM and the hedonic price models ought to provide a close approximation to the true economic value of changes in fish catch. It is true that this marginal price approach will underestimate non-marginal detrimental changes and will over-value beneficial non-marginal changes. Nevertheless, we believe that the error inherent in using the origin-specific marginal values is less serious than the error associated with the calculation of expected compensating variation using a single linear utility function. In this study, changes in total fish catch rates are generally small, while changes in the catch rates of individual taxa may be larger.

III. THE DATA

Study Area and Data

The data for this study are derived from the 1990 National Acidic Precipitation Assessment Program (NAPAP) sponsored by the Environmental Protection Agency (EPA) and the Department of Energy (DOE). The NAPAP Integrated Assessment Program was designed to determine and evaluate the impacts of acidic deposition (i.e., acid rain) on the environment. As part of the NAPAP, the DOE and EPA jointly sponsored the 1989 Aquatic Based Recreation Survey (ABRS, Shankle et al. 1990) which included the Freshwater Recreational Fishing Survey (FRFS). In all, fishing and personal data were collected from 1,147 individuals taking 14,664 fishing trips to 513 lakes. The study that follows uses a subset of these data for 6,654 trips for individuals living in Maine, New Hampshire, Vermont, and New York (excluding New York City). A detailed description of the data can be found in Shankle et al. (1990).

The ABRS data come from random phone surveys of residents in 40 counties in four states in the northeastern United States (see Table 5): 6 counties in Maine, 4 counties in New Hampshire, 24 counties in New York, and 6 counties in Vermont. Respondents were surveyed initially to determine personal characteristics and whether the respondents expected to fish during the summer of 1989. Two follow-up surveys collected more personal data on respondents, asked for impressions of the sites visited, and ascertained information used to determine the travel distances for each visit to a fishing site. Of the 40 counties surveyed, 2 were dropped due to insufficient responses (the 2 counties of Long Island) and 11 due to lack of variation in the attributes of lakes visited. The study treats each county as a single origin—the primary unit of analysis.

The travel costs used in this study are in terms of one-way miles from an origin to a site. Other travel costs (e.g., travel time) are assumed to be proportional to travel distance. A single travel cost value is calculated for each origin-site pair where the domain of the sites is given by the actual sites visited.

Ecological, Physical, and Climatic Data

As part of the ABRS, anglers were asked to report their actual total fish catch, by species, for each fishing trip during the summer of 1989. The catch per unit effort (CPUE) was found by dividing total catch per trip by the reported number of hours of fishing per trip. An average CPUE for each lake, by species, was found by averaging across all visits by all anglers to a given lake. In this study, three species-specific CPUEs are used: mean CPUE for rainbow trout (rain), mean CPUE for all trout other than rainbow trout (otrout), and mean CPUE for all pan fish (pan). Pan fish are all reported species other than trout, bass, pike, smelt, and eels. Trout and pan fish are included in the study because they have been shown to be important to anglers in the Northeast (Englin et al. 1991). The taxa ''trout'' was further divided into rainbow trout and all other trout to reflect the temperature sensitivity of rainbow trout. Finally, anglers were asked to report the number of boat ramps at each lake. The average number of ramps reported for each lake is given by the variable ramp.

The physical and chemical lake data are derived from the Eastern Lake Study (ELS, see Shankle et al. 1990 for a description of these data). The intersection between the ABRS lakes and the ELS lakes (the intersection lakes) contains 32 lakes and forms the basis for all of the ecological models. Climatic data for the intersection lakes comes from county-specific temperature and precipitation seasonal averages (Williams et al. 1996). Climatic parameters for a doubling of atmospheric carbon dioxide come from interpolations based on the predictions of the global climate circulation models of the Goddard Institute for Space Science and Oregon State University (Williams et al. 1996). The GISS and OSU models of global climate were chosen for three reasons. First, these models are commonly used in the prediction of climate change (e.g., Minns and Moore 1992, use GISS and OSU models). By using the GISS and OSU models, our results are comparable to other analyses of climate change including studies of climate change and agriculture by Mendelsohn, Nordhaus, and Shaw (1994) and climate change and energy by Morrison and Mendelsohn (1996). Second, the GISS and OSU models make somewhat different predictions about temperature and precipitation changes. The differences in the predictions of these models will serve as a ''sensitivity analysis'' for the current study. Third, the climate predictions of the GISS and OSU models have been modified by Williams et al. (1996) to permit

TABLE 2
SUMMARY STATISTICS FOR CLIMATE CHANGE PREDICTIONS

	Global Climate Circulation Model	
	OSU	GISS
Predicted Change in Temperature (°C)		
Mean January	4.52	5.59
Mean April	1.78	4.61
Mean July	2.95	3.87
Mean October	3.52	3.13
Predicted Change in Precipitation (centimeters)		
Mean January	0.91	0.38
Mean April	0.61	−0.13
Mean July	0.99	0.33
Mean October	1.78	−2.67

county-specific climate change predictions. Table 2 gives the predicted changes in temperature and precipitation parameters given by the two models as averaged over all of the counties considered in this study.

IV. THE RESULTS

Results of the Ecological Models

Table 1 gives the estimated coefficients for the ecological models. In all cases, the estimated coefficients are consistent with ecological conventional wisdom pertaining to each fish species group. The explanatory power of the ecological models of catch rate for the two trout species groups (rainbow trout and all trout other than rainbow trout) compare favorably with the fish yield models of Minns and Moore (1992). The r^2 values for the two trout models in the current study are 0.47 and 0.72 for rainbow trout and all trout other than rainbow trout, respectively. The highest reported r^2 in the Minns and Moore study (1992) is 0.42 for Northern Pike. Only a weakly positive relationship between climate variables and the catch rate for pan fish could be found—a finding consistent with the broad diversity and climate insensitivity of the composite species group.

Rainbow trout. The model estimates for rainbow trout show that rainbow trout are negatively affected by increases in mean July temperatures. This finding is consistent with the conventional wisdom that rainbow trout is a cold-water species (Englin et al. 1991). The model estimation also indicates that rainbow trout are affected positively by increased April precipitation and the amount of leafy vegetation surrounding a lake's margin. Once again, these findings are consistent with the "cold-water" affinity of rainbow trout since increased April precipitation is likely to increase cold water input into lakes from snow-melt. The positive relationship between leafy vegetation and rainbow trout catch rate is consistent with ecological wisdom that would predict the importance of shade to a cold-water fish.

All trout other than rainbow trout. Catch rates of "all trout other than rainbow trout" appear to be positively affected by increases in October temperature. These findings are consistent with the predictions of Regier and Meisner (1990) in which the authors predict that brook trout (*Salvelinus fontinalis*) living at high latitudes will benefit from longer summers. Brook trout is an important constituent of the group "all trout other than rainbow trout." All of the coefficients in the model are statistically significant at the 0.05 percent significance level. The negative sign on stratification indicates that these trout species do more poorly when their habitat is limited by lake stratification.

Pan fish. Only a modest link between climate and the catch rate of pan fish could be found. The model specification that had the most explanatory power ($r^2 = 0.14$) reveals that pan fish benefit slightly (but statistically significantly) from an increase in the mean April temperature. (Specifications using other seasonal temperatures revealed no significant relationship between temperature and catch rate.) The modest sensitivity of pan fish to climate is consistent with the composite nature of the species aggregation. The constituent species of the group "pan fish" include warm-water and cold-water species.

Comparison to other ecological models of fish yield. To our knowledge, the ecological results presented above represent the only estimated climate/ecological models of fish catch or yield for trout and pan fish in the northeastern United States. Nevertheless, we can compare the magnitude of our results to other climatic studies of freshwater lakefish. Many empirical studies show positive relationships between fish abundance or growth and temperature, provided that temperature increases do not exceed physiological limits. The results in the present study are applicable only to fish resident in lakes of northeastern United States. Because the study area lies within a relatively high range of latitudes, we would expect that most of the lake habitats in the study area would exhibit climatic maxima well below the physiological limits of the fish taxa in these models. This implies that many fish populations should benefit from an increase in temperature. As described above, we find that catch rates of "all other trout" and "panfish" do increase with temperature. The percentage increases in catch rates predicted for a doubling in CO_2 range from 12 percent in Vermont to 71 percent in New York for "all trout other than rainbow trout." Catch rates are predicted to increase more modestly for pan fish (from 3 percent in Vermont to 31 percent in Maine). These increases are more modest than those of other empirical studies. Minns and Moore (1992) estimate yield models for lake whitefish, northern pike, and walleye. For a change in temperature of 4°C, the authors' models would predict increases in yield of 110 percent, 158 percent, and 80 percent, respectively. Meisner et al. (1987), reporting on a study by Schlesinger and Regier (1982), find that a mere 2°C temperature increase would result in a 26 percent increase in the yield of a mixed species aggregate of freshwater lake fish. Shuter and Post (1990) predict that a 4°C increase in mean annual air temperature would lead to an unspecified increase in the range of yellow perch and smallmouth bass in central and western North America. Our study finds, however, that "rainbow trout" will be pushed beyond its physiological maxima in some lakes within the study area. For a doubling of CO_2, our models predict that rainbow trout catch rates may decline between 7 percent and 62 percent (although the GISS model predicts an increase of over 57 percent for rainbow trout in Maine).

The Geographic Implications of Predicted Changes in Fish Catch Rates

Under both the OSU and GISS scenarios of climate change, catch rates for "all trout other than rainbow trout" and "pan fish" are expected to be higher across the entire region (Table 3). The impacts of climate change on catch rates of "rainbow trout," however, depend on the global climate model and the county. Under the GISS scenario, rainbow trout catch rates increase in Maine as a result of climate change (this result is driven primarily by changes in precipitation) while catch rates for rainbow trout decline in New York, Vermont, and New Hampshire. Under both scenarios, rainbow trout populations remain at zero or are driven to local economic extinction (i.e., catch rate = 0) in many counties.

TABLE 3
BASELINE CATCH RATES AND MEAN PREDICTED CHANGE IN CATCH RATES (FISH/HOUR)

	Baseline Catch Rates			Mean Predicted Changes in Catch Rates: Under OSU Climate Change Predictions			Mean Predicted Changes in Catch Rates: Under GISS Climate Change Predictions		
State	rain	otrout	pan	rain	otrout	pan	rain	otrout	pan
Maine	0.07	0.22	0.16	−0.10	0.10	0.02	0.04	0.08	0.05
New Hampshire	0.29	0.21	0.25	−0.14	0.11	0.02	−0.02	0.08	0.05
New York	0.12	0.14	1.09	−0.09	0.11	0.02	−0.04	0.10	0.06
Vermont	0.27	0.66	1.52	−0.17	0.10	0.02	−0.03	0.08	0.05

Note: Data refer to origin of angler and not location of lake.

TABLE 4
Summary Statistics for Estimated Marginal Prices
(US$/trip assuming $0.25 per mile traveled)

	MP (rainbow trout)	MP (all trout other than rainbow trout)	MP (pan fish)	Mean Adjusted r^2
Mean HTC				.35
All prices	$19.11	$10.17	$2.95	
With insignificant prices set to 0	$41.82	$11.67	$3.34	
Mean RUM				n/a
All prices	$16.62	$3.07	−$7.08	
With insignificant prices set to 0	−$13.92	$18.80	−$2.38	
Number of Significant Positive and Negative Marginal Prices				
HTC	8+, 5−	10+, 4−	12+, 7−	
RUM	7+, 10−	9+, 5−	9+, 9−	

The Results of the Economic Models

The results of the RUM and HTC analysis are encouragingly similar in sign and magnitude. Table 4 gives the summary statistics for the marginal prices of fish catch rates from both the RUM and HTC models (results of the origin-specific estimations are available from the authors). Results are given in U.S. dollars based on an estimated travel cost of 25 cents per mile traveled. Since the results are proportional to distance, the reader may use other rates to convert the distance numeraire to currency. On average, both the RUM and HTC analyses show that a decline in the catch rates of most fish species would result in economic harm to anglers. The sign and magnitude of the marginal prices vary between origins. The mean marginal prices for the species in this study are well within the range found in previous studies of marine and freshwater sports fishing (e.g., see Karou et al. 1995; Morey, Shaw, and Rowe 1991; Morey et al. 1993; and Smith, Palmquist, and Jakus 1991). Both the RUM and HTC estimations reveal that each fish species may have both negative and positive marginal value depending upon the origin of the angler. Negative marginal prices are consistent with oversatiation of anglers with certain species of fish (see Pendleton et al. 1997). Negative prices also might result if anglers target a particular species other than the species with the negative price. Morey et al. (1991) found negative marginal prices for rockfish, bottomfish, and flatfish in the Columbia River and Morey et al. (1993) found negative marginal prices for salmon in the Penobscot River. Finally, an anonymous reviewer points out that a negative marginal value for a fish in this study only indicates that increasing the rate of fish catch (i.e., more fish) would reduce the utility of the average angler from that origin. This negative value says nothing about the marginal value of the fish to passive users or the value of the fish species in terms of its contribution to overall ecosystem production.

Welfare Estimates

Table 5 gives welfare estimates derived from the RUM and HTC models for two scenarios of carbon dioxide doubling (GISS and OSU models). All welfare estimates are per trip values in 1990 U.S. dollars. Our results show that climate change may have a detrimental effect on anglers from certain origins (e.g., Onandaga, New York) but will be beneficial for anglers from the majority of origins in the study area. The HTC models predict that anglers from more than half of the origins will experience a non-negative change in welfare due to the effects of a doubling of atmospheric carbon dioxide on fish catch rates.

TABLE 5
PER TRIP WELFARE ESTIMATES FOR SPORTFISHING UNDER A DOUBLING OF CO_2
(1990 US$)

				OSU		GISS	
ID	State	County	Population	RUM Estimates	HTC Estimates	RUM Estimates	HTC Estimates
1	Maine	Cumberland	243,135	−0.555	0.388	−1.682	0.971
2	Maine	Oxford	52,602	−0.065	−0.008	−0.254	−0.019
3	Maine	Piscataquis	18,653	0.032	0.029	0.033	0.071
4	Maine	Sagadahoc	33,535	2.784	1.529	0.749	0.799
6	Maine	Washington	35,308	0.082	0.028	0.114	0.165
7	New Hampshire	Belknap	49,216	1.059	0.020	0.259	0.050
8	New Hampshire	Cheshire	70,121	−0.019	0.004	0.060	0.009
9	New Hampshire	Coos	34,828	0.000	0.065	0.000	0.072
10	New Hampshire	Rockingham	245,845	0.000	7.451	0.000	5.798
11	New York	Allegany	50,470	0.000	0.235	0.000	0.248
13	New York	Cayuga	82,313	−0.053	−0.020	−0.029	−0.037
16	New York	Clinton	85,969	0.019	0.005	0.049	0.000
17	New York	Columbia	62,982	0.716	0.000	0.612	0.000
20	New York	Herkimer	65,797	0.000	−1.735	0.000	−0.564
22	New York	Livingston	62,373	0.003	−0.002	0.009	−0.005
23	New York	Madison	69,120	0.310	0.271	0.284	0.249
26	New York	Onondaga	468,973	−2.110	−5.590	−2.196	−4.121
27	New York	Orange	307,647	−0.070	0.000	−0.007	0.000
29	New York	Putnam	83,941	0.000	0.233	0.000	0.208
30	New York	St. Lawrence	111,974	0.267	−0.063	0.070	−0.001
33	New York	Wayne	89,123	1.316	0.004	1.081	0.013
35	Vermont	Bennington	35,845	0.000	−0.123	0.000	−0.030
36	Vermont	Chittenden	131,761	−1.802	−7.525	−0.467	−2.008
37	Vermont	Orange	26,149	0.000	−0.250	0.000	−0.048
38	Vermont	Orleans	24,053	0.143	−0.016	0.077	−0.029
39	Vermont	Washington	54,928	0.000	0.122	0.000	0.023
40	Vermont	Windsor	54,055	0.082	0.000	−0.052	0.000

The welfare estimates based on the marginal prices derived from the RUM models are similar to the HTC results when compared on an origin-by-origin basis. The RUM welfare estimates, like those of the HTC models, predict that anglers from more than half of the origins will experience a non-negative welfare change due to the effects of a doubling of atmospheric carbon dioxide on fish catch rates.

The economic impact of CO_2 doubling on freshwater fishing is not borne equally by the four states in this study. Anglers from New Hampshire and Maine are predicted to benefit, on average, from global warming (although the RUM estimates under the GISS scenarios show that anglers from Maine might suffer a welfare loss). The same models, however, predict that anglers from New York and Vermont will generally suffer economically due to global warming (although the RUM model predicts a modest welfare gain for anglers in New York under the OSU scenario of global climate change).

It is important to note that the welfare impacts reflect both differential climatic changes between these states and different fishing preferences by anglers from each state. Using the climatic results of the GISS and OSU models, the ecological models predict that Vermont could sustain greater declines in rainbow trout catch rates than other states. Similarly, the OSU-based models predict that the four states will experience similar changes in catch rates for rainbow trout, all trout other than rainbow trout, and pan fish.

Economic preferences for each species also play an important role in affecting the sign and magnitude of the county-specific welfare impacts. Recall that the origin-specific estimations in this study implicitly account for taste differences between origins and directly incorporate geographic differences. Both the HTC and RUM estimates show that some anglers place a negative value on certain fish species. Nearly all of the negative marginal values, from both the HTC and RUM estimations, occur for anglers living near the Finger Lakes and Lake Champlain. As mentioned before, negative prices may indicate that anglers are oversatiated with a particular fish species. In fact marginal prices and fish catch rates are negatively correlated for all HTG-estimated values and all RUM-estimated values except for those on pan fish. These negative prices may also indicate that anglers in these counties are targeting fish other than those with negative prices. Overall, the presence of negative prices in this study does not affect the sign of the welfare estimates aggregated across states or the region.

The per trip welfare estimates can be extrapolated over the entire region. Twenty percent of all those surveyed in the NAPAP study replied they would fish at least once during 1989. Of those that agreed to be interviewed further, on average anglers from Maine were found to make 19.8 trips/year, anglers from New Hampshire made 19.25 trips/year, anglers from New York made 13.4 trips/year, and anglers from Vermont made 11.0 trips/year. Table 6 gives sample welfare calculations for anglers from Maine. Based on the weighted average per trip welfare estimates, an average fishing participation rate of 20 percent, the average trips/year given above, and the state populations given by the 1990 Census, we can calculate the expected welfare impacts on all anglers from each state due to a doubling of atmospheric CO_2. Table 7 gives the results of these calculations. Three of the four models predict that global warming will benefit the region as a whole (estimates range from \$12.3 million to over \$20.4 million) with Maine and New Hampshire as the primary beneficiaries. Only the GISS model using the RUM prices shows a negative total welfare impact (−\$4.6 million). All models predict that Vermont will suffer losses in angler welfare (up to \$9 million in economic damage for anglers from Vermont). The RUM and HTC models, however, give mixed results for the impact of climate change on freshwater fishing in New York.

The most recent predictions about climate change indicate that by the year 2100 the expected change in mean annual temperature

TABLE 6
CALCULATING WELFARE CHANGE (MAINE)

$$\text{Weighted Mean Welfare Change per Trip} = \sum_j \left(\sum_i \Delta\text{CPUE(species } i) \times MPij \times \frac{\text{population(county } j)}{\sum_j \text{population (county } j)} \right)$$

Estimated Welfare Change per State = (Estimated # of anglers) × (mean trips/angler) × (weighted mean welfare change)

For *Maine* under GISS Scenario of CO_2 Doubling and HTC Prices:

County ID	ΔCPUE (rain)	ΔCPUE (otrout)	ΔCPUE (pan)	*MP* (rain)	*MP* (otrout)	*MP* (pan)	Population
1	−0.0093	0.0805	0.0500	0	0	30.616	243,135
2	0.0056	0.0809	0.0501	0	0	−2.7888	52,602
3	0.0742	0.0770	0.0501	2.71975	4.9322	17.3925	18,653
4	0.0142	0.0795	0.0501	−51.745	124.035	0	33,535
6	0.0914	0.0759	0.0502	7.7265	7.773	9.9515	35,308

Estimated # of Anglers in Maine 1,227,928
Mean Trips per Angler 19.84
Aggregate Welfare Change Due to Impact of CO_2 Doubling on Freshwater Sports Anglers in Maine = \$9,674,000

TABLE 7
TOTAL WELFARE IMPACT FOR RECREATIONAL FISHING UNDER A DOUBLING OF CO_2
(1990 US$ millions)

	2°C Change Only		OSU Prediction		GISS Prediction	
	RUM	HTC	RUM	HTC	RUM	HTC
Maine	$3.259	$6.502	$11.094	$9.580	−$5.063	$9.674
New Hampshire	$1.986	$18.641	$4.440	$32.174	$1.363	$25.302
New York	$0.218	−$8.007	$1.182	−$19.792	−$0.375	−$11.914
Vermont	−$0.833	−$4.097	−$1.951	−$9.640	−$0.547	−$2.587
Totals	$4.631	$13.040	$14.765	$12.322	−$4.622	$20.473

may not exceed 2°C (IPCC 1996). Table 7 gives the total welfare impacts that would result from a 2°C change, spread evenly across all seasons with precipitation held constant. Under this more modest scenario, the impact of climate change on freshwater fishing remains beneficial for the region with Maine and New Hampshire benefiting most from climate change. Again, Vermont is an unambiguous loser and the results for New York are mixed.

V. DISCUSSION AND CONCLUSION

This study uses global climate models, ecological models of fish catch rates, and economic models to show that the regional effects of global climate change could have mixed impacts on the welfare of anglers who fish for trout and pan fish in the northeastern United States. While the economic impact of global change on any single species group could be large, the combined impacts of global change on rainbow trout, all other trout, and pan fish tend to be moderate.

While we do not estimate the economy-wide impact of the effects of global warming on lake ecosystems, we do estimate that the impact of global warming on freshwater angling in the region is estimated to be beneficial for most of the models estimated. Depending on the climate scenario, estimates of the net effects for the region range from a $4.6 million loss to a $20.4 million benefit. Both climatic and economic factors drive the differential impact of climate change on the sportsfisheries of the four states. For many anglers, the economic damage from reduced populations of rainbow trout will be more than offset by increases in the catch rates of all other trout species. The distribution of economic impacts due to climate change, however, are not distributed evenly over the four states considered (Table 7). New York and Vermont bear the brunt of the economic damage that global climate change could inflict upon sportfishing, suffering combined economic damages that could be as high as −$29 million. Maine and New Hampshire, however, are likely to benefit substantially from global warming with combined net benefits as high as $41 million.

References

Bockstael, N., W. M. Hanemann, and C. Kling. 1987. "Estimating the Value of Water Quality Improvements in a Recreational Demand Framework." *Water Resources Research* 23: 951–60.

Brown, G., and R. Mendelsohn. 1984. "The Hedonic Travel Cost Method." *Review of Economics and Statistics* 66:427–33.

Dubin, J., and R. Rivers. 1990. *SST.* Statistical Software Tool.

Englin, J., and R. Mendelsohn. 1991. "A Hedonic Travel Cost Analysis for Valuation of Multiple Components of Site Quality: The Recreation Value of Forest Management." *Journal of Environmental Economics and Management* 21 (3):275–90.

Englin, J. E., T. A. Cameron, R. E. Mendelsohn, G. A. Parsons, and S. A. Shankle. 1991. "Valuation of Damages to Recreational Trout Fishing in the Upper Northeast Due to Acidic Deposition." Prepared for the Department of Energy by Pacific Northwest Laboratory.

Hausman, J., G. Leonard, and D. McFadden. 1995. "A Utility-Consistent, Combined Discrete Choice and Count Data Model: Assessing Recreational Use Losses Due to Natural Resource Damage." *Journal of Public Economics* 56:1–30.

Kaoru, Y., V. Smith, and J. Liu. 1995. "Using Random Utility Models to Estimate the Recreational Value of Estuarine Resources." *American Journal of Agricultural Economics* 77 (1): 141–51.

International Panel of Climate Change (IPCC). 1996. *Climate Change 1995: The Science of Climate Change.* Cambridge, UK: Cambridge University Press.

McCauley, R., and D. Kilgour. 1990. "Effect of Air Temperature on Growth of Largemouth Bass in North America." *Transactions of the American Fisheries Society* 119:278–81.

McFadden, D. 1978. "Modeling the Choice of Residential Location." In *Spatial Interaction Theory and Residential Location*, eds. A. Karlquist et al. Amsterdam: North-Holland.

Mendelsohn, R. 1984. "An Application of the Hedonic Travel Cost Framework for Recreation Modeling to the Value of Deer." *Advances in Applied Microeconomics* 3:89–101.

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. "The Impact of Global Warming on Agriculture." *American Economic Review* 84 (4):753–71.

Meisner, J., J. Goodier, H. Regier, B. Shuter, and J. Christie. 1987. "An Assessment of the Effects of Climate Warming on Great Lakes Basin Fishes." *Journal of Great Lakes Resources* 13 (3):340–52.

Meisner, J. 1990. "Effect of Climatic Warming on the Southern Margins of the Native Range of Brook Trout, *Salvelinus fontinalis*." *Canadian Journal of Fisheries and Aquatic Science* 47:1065–70.

Minns, C., and J. Moore. 1992. "Predicting the Impact of Climate Change on the Spatial Pattern of Freshwater Fish Yield Capability in Eastern Canadian Lakes." *Climatic Change* 22:327–46.

Morey, E., W. Shaw, and R. Rowe. 1991. "A Discrete Choice Model of Recreational Participation, Site Choice, and Activity Valuation When Complete Trip Data Are Not Available." *Journal of Environmental Economics and Management* 20 (2):181–201.

Morey, E., R. Rowe, and M. Watson. 1993. "A Repeated Nested Logit Model of Atlantic Salmon Fishing." *American Journal of Agricultural Economics* 75 (3):578–92.

Morrison, W., and R. Mendelsohn. 1996. "Assessing the Energy Costs of Climate Change: Evaluation of Impacts on the U.S. Energy Sector." Yale University School of Forestry and Environmental Studies.

Parsons, G., and M. Kealy. 1992. "Randomly Drawn Opportunity Sets in a Random Utility Model of Lake Recreation." *Land Economics* 68 (Feb.):93–106.

Parsons, G., and M. Needleman. 1992. "Site Aggregation in a Random Utility Model of Recreation." *Land Economics* 68 (Nov.):418–33.

Pendleton, L., B. Sohngen, R. Mendelsohn, and T. Holmes. 1997. "Measuring the Economic Value of Forest Attributes in the Southern Appalachian Mountains." Yale School of Forestry and Environmental Studies.

Regier, H., and J. Meisner. 1990. "Anticipated Effects of Climate Change on Freshwater Fishes and Their Habitats." *Fisheries* 15 (6): 10–15.

Schlesinger, D., and H. Regier. 1982. "Climatic and Morphoedaphic Indices of Fish Yields From Natural Lakes." *Transactions of the American Fisheries Society* 111:141–50.

Shankle, S., J. Englin, W. Monroe, D. Beck, M. Casinelli, H. Saunders, and S. Grover. 1990. "Freshwater Based Recreation in the Upper Northeast: Data Collection Documentation." Prepared for the Department of Energy by Pacific Northwest Laboratory.

Shuter, B., and J. Post. 1990. "Climate, Population Viability, and the Zoogeography of Temperate Fishes." *Transactions of the American Fisheries Society* 119:314–36.

Smith, V., and Y. Kaoru. 1987. "The Hedonic Travel Cost Method: A View from the Trenches." *Land Economics* 63 (Nov.):779–92.

Smith, V., R. Palmquist, and P. Jakus. 1991. "Combining Farrell Frontier and Hedonic Travel Cost Models for Valuing Estuarine Quality." *Review of Economics and Statistics* 73 (4):694–99.

Williams, L., D. Shaw, and R. Mendelsohn. 1996. "Evaluating GCM Output with Impact Models. Electric Power Institute, Palo Alto, CA.