ECONOMIC ANALYSIS OF THE POTENTIAL IMPACT OF CLIMATE CHANGE ON RECREATIONAL TROUT FISHING IN THE SOUTHERN APPALACHIAN MOUNTAINS: AN APPLICATION OF A NESTED MULTINOMIAL LOGIT MODEL

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Abstract. Global warming due to the enhanced greenhouse effect through human activities has become a major public policy issue in recent years. The present study focuses on the potential economic impact of climate change on recreational trout fishing in the Southern Appalachian Mountains of North Carolina. Significant reductions in trout habitat and/or populations are anticipated under global warming since the study area is on the extreme margins of trout habitat of the eastern U.S. The purpose of this study is to estimate the potential welfare loss of trout anglers due to global warming. A nested multinomial logit model was developed and estimated to describe the angler's fishing choice behavior. The estimated median welfare loss (Compensating Variation) ranged from \$5.63 to \$53.18 per angler per single occasion under the various diminished trout habitat and/or population scenarios.

1. Introduction

Economic development has long been recognized as a cause of adverse environmental effects at the local and the regional level. In recent years, it has become clear that expanding economic activity can also impose environmental damage that is global in dimension and irreversible even over a long time horizon (Cline, 1992). The enhanced greenhouse effect[1] is a major example of these global environmental impacts.

The Intergovernmental Panel on Climate Change (IPCC) believes that the enhanced greenhouse effect will cause significant global warming by the middle of the next century in the absence of policy intervention. By the end of the next century, with a doubling of atmospheric carbon dioxide (CO_2), the average global

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temperature is expected to increase by 1.5 to 4.5 °C (2.7 to 8.1 °F) based on projections from general circulation models (GCMs)[2] (IPCC, 1990). The anticipated consequence of this warmer world will be global ecosystem changes accompanied by socio-economic effects. These changes would likely force society to make far-reaching decisions regarding the management and allocation of natural resources to adapt to and mitigate global warming.

Numerous studies have addressed the potential impacts of climate change on ecological systems. However, socio-economic assessment of these impacts has been largely neglected.[3] This neglect may be due, in part, to the complexity of the problem. Even though substantial progress has been made toward measuring the economic values of natural resources, it is still a complex matter to put dollar values on ecological damages from human-caused disturbances on ecosystems. However, recreational freshwater fishing is one area where there is enough information to develop estimates of the physical impacts on ecosystems resulting from global warming and the related estimates of effects on human welfare. The physical relationship between fish population and water quality, especially water temperature, has been well established from laboratory experiments and field observations and measuring human welfare through recreational fishing activities has been the subject of extensive study in recreation economics.

The purpose of the present study is to conduct an economic analysis of the potential impacts of climate change on recreational trout fishing in the Southern Appalachian Mountains of North Carolina. An important feature of the study area is that this region is regarded as the natural southern limit of trout habitat in the eastern United States. Therefore significant decreases in trout habitat and population could be expected if global warming occurs. Due to the anticipated significant trout habitat loss, anglers' welfare losses from trout fishing could be also significant. The main objective of this study is to estimate trout anglers' welfare losses based on the scenarios of the potential reductions of trout habitat in the Southern Appalachian Mountain region of North Carolina using a nested logit model framework.

2. Effects of Global Warming on Trout Ecosystems

Mountain streams in North Carolina offer anglers a variety of trout fishing opportunities. Streams in the state are more capable of supporting brook, brown and rainbow trout than those in any other southeastern state in the U.S. (Jacobs, 1994). The brook trout (*Salvelinus fontinalis*) is the only coldwater species native to North Carolina. The brook trout once was widely distributed throughout the mountain counties of North Carolina; however, because of the lowering of water quality in the creeks and the competition with introduced species such as rainbow and brown trout, its range is now significantly reduced. Rainbow trout (*Oncorhynchus mykiss*), which is native to the Rocky Mountains, was introduced into North Carolina as early as the 1880s. Since then it has been stocked in most trout waters in the state and has become the backbone of the trout fishery in North Carolina. Brown trout (*Salmo trutta*), native to northern Europe, was imported from Germany and Scotland in the late 1800s. It was first stocked in North Carolina shortly after 1905, but was never as widely distributed as the rainbow (Manooch, 1984). In the streams of North Carolina, the brown trout is usually present in the deep and calm pools of lower elevation. In the midsection of the stream, the rainbow trout takes over as the most plentiful trout. If brook trout still exist in the stream, it is found in the headwaters where the creek is small, cold, and clean.

The ability of a trout to survive depends on the several factors such as water temperature, dissolved oxygen content, salinity, and the acidity of the water (McCauley, 1991). These factors affect the quality of a water body and thus its suitability as trout habitat. Water temperature is believed to be one of the most important physical factors pertaining to the survival of trout. Global warming is expected to increase water temperature of trout streams and the solubility of oxygen in the stream decreases with rising water temperature.

The impacts of global warming on coldwater fishery ecosystems, especially those of the brook trout, have been examined widely over the past two decades. Following Meisner's pioneering works (1988, 1990a, 1990b) investigating the relationship between global warming and the coldwater fishery ecosystem, Flebbe (1993) evaluated the loss of the native brook trout habitats of the North Carolina and Virginia due to global warming. With a GISS[4] warming scenario of 3.8 °C increase in mean annual air temperature, Flebbe estimated that out of 528 streams in Virginia only 58 would still have brook trout, a loss of 89% of the brook trout streams. In North Carolina, 26 out of 148 streams would retain brook trout, a loss of 82% under the same warming scenario.

Keleher and Rahel (1996) calculated potential salmonid – rainbow, brown, brook, and cutthroat trout – habitat loss due to global warming using geographic information system (GIS) approach in Rocky Mountain region. The region includes 8 states (Idaho, Montana, Wyoming, Nevada, Utah, Colorado, New Mexico, and Arizona). In addition to the regional analysis, they did a separate analysis for the state of Wyoming. They produced potential salmonid habitat loss estimates for Wyoming as well as for the Rocky Mountain region as a whole. According to their estimates, for increases of 1, 2, 3, 4, or 5 °C in mean July air temperature, the geographic area suitable for samonid habitat would be reduced by 16.2, 29.1, 38.5, 53.3, or 68.0% in Wyoming and 16.8, 35.6, 49.8, 62.0 or 71.8% in the Rocky Mountains, respectively. This loss of geographic range would correspond to reductions of 7.5, 13.6, 21.0, 31.4, or 43.3% in the length of streams supporting suitable salmonid habitat in Wyoming.

Brogan (1997)[5] employed a Delphi survey method to summarize the professional opinions regarding potential impacts of climate change on Southern Appalachian coldwater fisheries. According to his study, most of the panel participants agreed that trout habitat would shrink and retreat toward headwater streams because of inhospitable aquatic conditions induced by global warming. The maximum habitat loss estimates for each species was 50% for brown and rainbow trout and 30% for brook trout.[6] The median estimates were 10% for brook and rainbow trout and 5% for brown trout. Interestingly, these figures are far smaller than the estimates from Flebbe's study. In summary, there is consensus among researchers that global warming would have negative effects on trout ecosystems and would reduce trout habitats pushing trout ranges up to headwater streams in higher elevations. Unfortunately, however, many discrepancies exist in the amount of change across the studies.

3. Methodology

A new phase in recreation economics began with the introduction of the random utility models (RUMs)[7] to describe an individual's recreation behavior. RUMs use a different approach than traditional travel cost models to explain an individual's recreation behavior. RUMs focus on modeling the choice among substitute alternatives on a given occasion rather than estimating directly the demand function for a site. Consider the indirect utility function of an individual for a single recreational occasion. On any given choice occasion, decisions to visit different sites are mutually exclusive. RUMs assume that an individual faces a decision among discrete, quality-differentiated sites and the individual chooses the site, which maximize his/her utility on any given occasion. The probability of choosing a site can then be expressed as a function of the characteristics of sites.

An advantage of using RUMs is that they are capable of not only measuring the welfare changes from changes in site quality but also incorporating substitution effects among sites. The latter is difficult to capture in the traditional travel cost method framework. With this context, RUMs are particularly advantageous in the study of the recreational sports fishing since numerous sites are usually available for recreational sport fishing, thus they can be substituted for one another. However, the gain in the ability to describe choices among sites given an occasion comes at the cost of more complexity in explaining the allocation of trips an individual takes to a site over a season. Morey et al. (1993) have developed the repeated discrete choice model to resolve this issue based on the notion that a fishing season can be divided into a finite number of periods and each period is a choice occasion. Thus it is assumed that each choice occasion represents a choice to fish or not to fish and angler's decisions on whether and where to fish repeat for an each choice occasion over the entire season.

A number of studies have employed RUMs to address the research issues associated with recreational sport fishing. Most of these applications have evaluated the benefits from the increase in catch rate due to water quality improvements or have estimated potential welfare changes from different resource management practices. The following two sections represent the basic theory and estimation process of nested logit model and illustrate welfare measurement calculation.

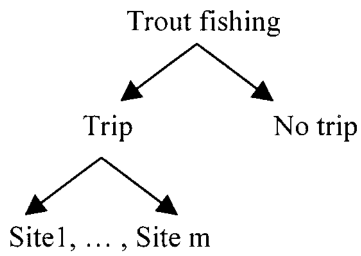

Figure 1. Nesting structure.

3.1. NESTED MULTINOMIAL LOGIT MODEL

Assume the classical model of the rational, utility-maximizing individual. Suppose an individual considers a trout-fishing trip and there are two levels of decisions one should make for the trip.[8] The first decision is whether to participate in the fishing trip. Given the participation decision, the next decision is to choose a site for the trip (Figure 1).

Suppose U is the utility of a trout angler associated with a trout-fishing trip, then his/her utility can be represented as follows:[9]

$$U_{fi} = \beta' X_i + \gamma' Z_f + \varepsilon_{fi}\,, \tag{1}$$

where f is y for trip or n for no trip and i is site $(1, \ldots, m)$. ε_{fi} is an unobservable error term. β and γ are the parameter vectors to be estimated and X_i and Z_f are observed site and individual characteristics, respectively.[10] Let $\langle\varepsilon\rangle$ denote the vector $[\varepsilon_{y1}, \varepsilon_{y2}, \ldots, \varepsilon_{ym}, \varepsilon_n]'$. If random errors are assumed to follow a generalized extreme value (GEV) distribution then the cumulative distribution function (CDF) for $\langle\varepsilon\rangle$ given the nesting structure in Figure 1 is:

$$F(\langle\varepsilon\rangle) = \exp\{-[\exp(-\varepsilon_{y1}/\theta) + \exp(-\varepsilon_{y2}/\theta) + \cdots + \exp(-\varepsilon_{ym}/\theta)]^{\theta} - \exp(-\varepsilon_n)\}, \tag{2}$$

where the common parameter θ can be interpreted as an index of the similarity of the alternatives at site choice level and is estimated as the coefficient of the inclusive value. According to McFadden (1978) relating the generalized extreme value distribution to stochastic utility maximization, a sufficient condition for a nested multinomial logit model to be consistent with stochastic utility maximization is that the coefficient of inclusive value lies in the unit interval.

Recall the joint probability that an angler will fish at a specific site i can be represented as the product of a conditional probability and a marginal probability shown in Equation (3):

$$\text{prob}(y \cdot i) = \text{prob}(y) * \text{prob}(i/y)\,. \tag{3}$$

The likelihood function for the sample is:

$$L = \prod_{k=1}^{K} \left\{ \prod_{i=1}^{m} [\text{prob}(y \cdot i)]^{T_i} \right\} * [\text{prob}(n)]^{T_n}\,, \tag{4}$$

where k is an individual in the sample. T_i is 1 if site i is visited, 0 otherwise and T_n is 1 for no trip, 0 otherwise. The estimates of parameters are obtained by maximizing this likelihood function using a sequential estimation technique.

With the indirect utility function specified in Equation (1), the conditional probability that an angler will visit site i contingent on the decision to go fishing (y) for a given occasion is given by:

$$\begin{aligned}\text{prob}(i/y) &= \frac{\exp[(\beta' X_i + \gamma' Z_y)/\theta]}{\sum_{j=1}^{m} \exp[(\beta' X_j + \gamma' Z_y)/\theta]} = \frac{\exp[\beta' X_i/\theta]}{\sum_{j=1}^{m} \exp[\beta' X_j/\theta]} \\ &= \frac{\exp[\beta' X_i/\theta]}{\exp[IV]},\end{aligned} \tag{5}$$

where the inclusive value (IV) is defined as:

$$IV = \ln\left[\sum_{j=1}^{m} \exp[\beta' X_j/\theta]\right]. \tag{6}$$

Then, the probability of taking a trip is given by:

$$\begin{aligned}\text{prob}(y) &= \frac{\left\{\sum_{j=1}^{m} \exp[(\beta' X_j + \gamma' Z_y)/\theta]\right\}^{\theta}}{\left\{\sum_{j=1}^{m} \exp[(\beta' X_j + \gamma' Z_y)/\theta]\right\}^{\theta} + \exp[\gamma' Z_n]} \\ &= \frac{\exp[\gamma' Z_y + \theta IV]}{\exp[\gamma' Z_y + \theta IV] + \exp[\gamma' Z_n]}\end{aligned} \tag{7}$$

or, conversely,

$$\text{prob}(n) = 1 - \text{prob}(y) = \frac{\exp[\gamma' Z_n]}{\exp[\gamma' Z_y + \theta IV] + \exp[\gamma' Z_n]}. \tag{8}$$

A benefit of the nested logit model is that it permits a certain degree of correlation among the error terms by allowing the inclusive value to have a coefficient other than one. The nested logit model relaxes the independence assumption among the error terms in the simple multinomial logit model and allows a pattern of dependence among the choices so that it mitigates the shortcomings associated with the independence from irrelevant alternatives (IIA) property[11] implicit in the multinomial logit model. It is apparent from Equations (5)–(7) that the model goes back to a simple multinomial logit model if θ is equal to one. The closer θ is to zero, the more the choices within a nest are close substitutes. A desirable feature of estimating the coefficient of the inclusive value is that the magnitude of θ and associated t statistic provide information on the substitution possibilities among the choices within a nest.

3.2. WELFARE MEASUREMENT[12]

In the random utility model framework, an individual's indirect utility function is used to obtain the monetary welfare measurement – compensating variation (CV) – from the changes in any explanatory variables. One definition of CV, which has been used frequently in recreation demand studies, is the 'payment' which equates the expected values of the maximum indirect utility functions of an individual before and after the changes in site quality. The CV for an individual k with this notion is defined implicitly by:[13]

$$E[V_k(y_k - p - CV_k, q^1)] = E[V_k(y_k - p, q^0)]\,, \tag{9}$$

where

$$\begin{aligned} V_k(y_k - p, q^0) \;=\; & \max[V_{1k}(y_k - p_{1k}, q_1^0) + \varepsilon_{1k}, V_{2k}(y_k - p_{2k}, q_2^0) + \\ & + \varepsilon_{2k},\; \ldots,\; V_{mk}(y_k - p_{mk}, q_m^0) + \varepsilon_{mk}] \end{aligned} \tag{10}$$

y_k is an individual k's income and p_{ik} is an individual k's travel cost to site i. q_i^0 is the quality of site i before the change and q_i^1 is the quality of site i after the change. With the nested multinomial logit model, the CV is obtained by the following formula using expected maximum utility given that the marginal utility of income is constant.

$$\begin{aligned} CV \;=\; & \frac{1}{-\beta_0}[\ln[\exp(\gamma' Z_y + \theta IV^1) + \exp(\gamma' Z_n] - \\ & - \ln[\exp(\gamma' Z_y + \theta IV^0) + \exp(\gamma' Z_n)]]\,, \end{aligned} \tag{11}$$

where β_0 is the coefficient of price – the marginal utility of income. The superscript 0 and 1 represent 'before' and 'after' changes in site quality. Note that Equation (11) provides a welfare measure associated with a single trip occasion. Since the non-participation option was available, seasonal value can be approximated by multiplying the single occasion value by the total number of occasions in a season.

4. Data, Model Specification and Scenarios

4.1. DATA

Approximately 4,000 miles of streams contain trout in the Southern Appalachian Mountain area in North Carolina and about half of this is open to public fishing. A total of 250 streams are available for trout fishing according to the North Carolina Wildlife Resource Commission (NCWRC) and most of these streams are located in the Nantahala and Pisgah National Forests and the Great Smoky Mountains National Park.

Information on angler's trout fishing experience, characteristics, and preferences was obtained from the '1996 North Carolina Mountain Trout Angler

Survey'.[14] This was conducted as a mail survey in November 1996 to describe the current status of angler's experiences and attitudes toward mountain trout fishing in North Carolina. Questionnaires were mailed to 1,400 people who held North Carolina trout fishing licenses. A total of 546 questionnaires were returned (39% response rate). For the anglers who took a trip during the past 12 months, specific information for their last trip was collected regarding trip destination, travel distance, fishing gear and bait used, preference structure and demographic characteristics. For those trout anglers who did not take a fishing trip during the past 12 months, only socio-economic characteristics were gathered.

Site characteristic information – the overall water quality classification of stream and the length of stream – was acquired from NCWRC. Information on the trout population of each stream was taken from 'Survey and Classification of State-Managed Trout Streams (1983)'. To compute travel distance, the zip code of the angler's home and latitudes and longitudes of sites were entered into ZIPFIP software. The individual choice set was assumed to be the 97 streams visited.

4.2. MODEL SPECIFICATION

This section explains the specification of the angler's indirect utility function for the nested multinomial logit model. Contingent on the decision to go trout fishing, the conditional probability of choosing a specific site i, $\text{prob}(i/y)$, depends on site characteristics. The utility for an angler derived from the site choice is specified as:

$$V_{yi} = \beta_0(\text{Pr}ice_i) + \beta_1(WQhigh_i) + \beta_2(WQmed_i) + \beta_3(Miles_i) + + \beta_4(Crop_i) + \beta_5(dW_i)\,. \tag{12}$$

The independent variables are defined in Table I. β_0 should be negative and β_1 and β_2 are expected to be positive since anglers are likely to choose a better quality of stream. Dummy variable, *WQlow*, was not included in the equation to avoid a multicollinearity. β_3 and β_4 are also presumed to be positive and there is no prior expectation on the sign of β_5.

The probability of taking a trip or not taking a trip depends upon the comparison of the utilities expected from 'going trout fishing' and 'not going trout fishing'. If the benefits from going fishing are greater than those from doing something else, which could include other leisure activities as well as working, then one will go fishing. Angler characteristics such as the individual's income and age were used to explain the utility associated with the participation decision (Equation (13)).

$$V_f = \gamma_0(Income) + \gamma_1(age). \tag{13}$$

Variable *Income* and *Age* were interacted with a participation dummy variable *dP* (*dP* is 1 if individual took a trip, 0 if not). Otherwise, γ_0 and γ_1 can not be estimated since individual characteristics do not vary over participation choices. The sign of coefficient on the variable *income*, γ_0, is anticipated to be positive, however there is no prior expectation on the sign of γ_1.

TABLE I
Definitions of variables

Variable	Definition
Price	Round trip travel cost =
	(0.3 ∗ roundtrip distance) + (round trip distance/40 mph) ∗ (wage/2080) ∗ (1/3)
WQhigh	1: if stream is high quality trout stream capable of sustaining a fishery
	through natural reproduction alone, 0: otherwise
WQmed	1: if stream is intermediate quality streams incapable of sustaining
	fishery through natural reproduction alone, 0: otherwise
WQlow	1: if stream is low quality stream that can support trout on a year round basis
	but in which no wild trout are found or streams better managed for warm-
	water species, 0: otherwise
Miles	Length of stream (miles) supports trout
Crop	The poundage trout present/acre
dW	1: if wild trout water, 0: otherwise (hatchery supported stream)
Income	Individual's income level (before tax, in 1995 dollars)
	1: less than $10,000
	2: $10,001–$25,000
	3: $25,001–$50,000
	4: $50,001–$75,000
	5: $75,001–$100,000
	6: more than $100,000
Age	Individual's age
	1: under 20
	2: 20's
	3: 30's
	4: 40's
	5: 50's
	6:over 60's

4.3. SCENARIOS

Global warming is expected to decrease the site quality for trout fishing through an increase in stream water temperature and the related decrease in dissolved oxygen level. These water quality degradations are likely to decrease trout habitat and population in the stream. The anticipated decrease in physical trout habitat can be incorporated into the economic model through the reduction in the variable *Miles*. The effect of the reduction of trout abundance in the stream can be incorporated into the model through the decrease in variable *Crop*.

Considering the great deal of uncertainty involved in the global warming phenomena itself and the discrepancies in the estimates of trout habitat loss due to global warming across studies, it is worthwhile to evaluate various scenarios reflecting diverse possibilities. Three sets of scenarios were constructed from the trout habitat assessment studies described in Section 2. The first scenario was based on the Flebbe (1993)'s brook trout habitat loss estimate (loss of 82%) in the North Carolina streams due to global warming. A problem with this scenario is that Flebbe (1993) investigated only brook trout habitat loss because brook trout are the only species native to North Carolina. Brook trout are known to be the least tolerant to warm water temperature among the three species and to require the most water quality. Thus, a welfare measure with this scenario is likely to overestimate angler's welfare loss.

The second set of scenarios consisted of the habitat loss estimates in Wyoming from Keleher and Rahel (1996). Habitat loss estimates in Wyoming were 7.5, 13.6, 21.0, 31.4, and 43.3% for 1, 2, 3, 4, and 5 °C increases of mean July air temperature, respectively. Wyoming habitat loss estimates are represented in terms of reduction of the stream length. One advantage of using the results from this study is that they estimated a spectrum of samonid habitat loss according to the several different global warming scenarios instead of using a single temperature projection from a certain GCM. However, this advantage is overshadowed by the fact that their study area was far from Southern Appalachia, and it is difficult to assume that same magnitudes of habitat loss would occur in Southern Appalachia.

The last set of scenarios considered the median habitat loss estimates from the Delphi survey by Brogan (1997). Brogan (1997) is the only comprehensive study, which deals with the effects of climate change on all three trout species in the Southern Appalachian Mountains. However, a weakness of this scenario is that these estimates depend on experts' subjective opinions rather than results from empirical works. All scenarios are summarized in Table II.

5. Results

5.1. PARAMETER ESTIMATES

The signs of the parameter estimates of both site choice and participation choice stages are consistent with the prior expectations and all the parameter estimates are statistically significant (Table III). The coefficients on *WQhigh* and *WQmed* are positive, significant, and approximately equal indicating that good water quality is important to the site choice decision but anglers do not differentiate on whether or not the stream can support natural reproduction. The stream type dummy variable (*dW*) had a negative sign, which suggests that anglers in the sample prefer to go to hatchery supported streams rather than to wild trout water. The coefficient on the variable *age* turned out to be negative implying that younger anglers are more

TABLE II
Summary of trout habitat/population loss scenarios

Source	Climate scenario	Habitat loss scenario
Flebbe (1993)	+3.8 °C in mean temp.	(1) 82% brook trout habitat loss
Keleher and Rahel (1996)	+1 °C in July air temp.	(2) 7.5% habitat loss
	+2 °C in July air temp.	(3) 13.6% habitat loss
	+3 °C in July air temp.	(4) 21.0% habitat loss
	+4 °C in July air temp.	(5) 31.4% habitat loss
	+5 °C in July air temp.	(6) 43.3% habitat loss
Brogan (1997)[a]	+4.6 °C in mean temp.	(7) 8.3% habitat loss
	25% reduction of stream flow	(8) 17.5% population loss
		(9) 8.3% habitat and 17.5% population loss

[a] Median estimates of habitat or/and population loss were used for scenario (7)–(9).

TABLE III
Parameter estimates from site and participation choice[a]

Variable	Coefficient estimate	Standard error	t-ratio
Price	–0.0095	0.0009	–9.851
WQhigh	0.9779	0.2587	3.780
WQmed	0.9389	0.1520	6.177
Miles	0.0770	0.0077	9.934
Crop	0.0257	0.0052	4.930
dW	–0.5088	0.1951	–2.608
Income	0.2309	0.0695	3.321
age	–0.2446	0.0694	–3.354
IV	0.1912	0.0407	4.697[b]

[a] For the site choice, the dependent variable is equal to 1 if angler visited a particular site, 0 otherwise. For the participation decision, the dependent variable is equal to 1 if angler chose to go fishing trip, 0 if angler did not take a trip.
[b] t-statistic for H_0: $\theta = 1$ is –19.87.

likely to participate in a fishing trip. The estimate of θ is 0.19, which satisfies McFadden's (1978) sufficient condition for a nested logit model to be consistent with stochastic utility maximization. The magnitude of the estimate of θ is close to zero indicating that fishing sites are close substitutes for one another. Also, θ is significantly different from 1 implying that a simple multinomial logit model would not be appropriate.

TABLE IV

Per occasion and yearly welfare loss estimates (in 1995 dollars)

Habitat loss scenario[a]	Median loss per occasion[b]	Mean yearly loss[c]
(1) 82% habitat loss	$53.18 ($0.004 –$145.12)	$2692 ($0.2 –$7546)
(2) 7.5% habitat loss	$10.66 ($0.0006– $17.19)	$474 ($0.03– $894)
(3) 13.6% habitat loss	$17.85 ($0.001 – $30.52)	$813 ($0.05–$1587)
(4) 21.0% habitat loss	$25.00 ($0.001 – $45.58)	$1168 ($0.05–$2354)
(5) 31.4% habitat loss	$32.65 ($0.002 – $63.86)	$1577 ($0.1 –$3320)
(6) 43.3% habitat loss	$39.12 ($0.002 – $84.28)	$1942 ($0.1 –$4382)
(7) 8.3% habitat loss	$11.71 ($0.0007– $18.97)	$521 ($0.03– $986)
(8) 17.5% population loss	$5.63 ($0.002 – $11.70)	$285 ($0.1 – $608.4)
(9) 8.3% habitat and 17.5% population loss	$18.41 ($0.003 – $24.72)	$833 ($0.15–$1285)

[a] For the detail of each scenario, refer to Table II.
[b] Numbers in parentheses are the ranges of the estimates.
[c] Numbers in parentheses are the ranges of the estimates.

5.2. ESTIMATES OF WELFARE LOSS PER OCCASION AND YEAR

The median angler’s consumer surplus value in 1995 dollars for a trip occasion is $266. This is interpreted as the value an angler places on a single trout-fishing trip occasion. CV measures reported in Table IV can be interpreted as the trout angler’s welfare loss in dollar terms based on the trout habitat and population reduction scenarios. Median estimate of the trout angler’s welfare loss under Flebbe’s scenario (scenario (1)) is $53.18 per single trip occasion and turned out to be the largest angler loss estimate as expected. Under the second set of scenarios (scenarios (2)–(6)), median welfare loss per occasion are $10.66, $17.85, $25.00, $32.65, and $39.12 and these estimates correspond to 7.5, 13.6, 21.0, 31.4, and 43.3% trout habitat loss, respectively. With Delphi survey habitat loss scenarios (scenarios (7)–(9)), median angler’s welfare loss estimates are $11.71, $5.63, and $18.41 per occasion, respectively. Up to scenario (7), only physical trout habitat loss in terms of the reduction of stream length has been considered. The reduction of trout abundance in the streams has been examined in scenario (8) and (9). Comparing the welfare measurement of scenario (7) with that of (8), it is found that a loss of trout habitat has bigger impacts on welfare measure than the loss of trout population in the stream because the coefficient estimate of *Miles* is larger than that of *Crop*. This is plausible because the former represents the complete loss of the lower portion of streams, whereas the latter represents reductions in trout population but not the complete loss of fishing areas.

These welfare losses are per trip occasion. It would be interesting to consider losses over the season. This requires knowing the number of potential trip occasions in a season. Mountain trout streams in North Carolina are open to the public all year round. Access is prohibited for a few months in the spring for hatchery supported streams,[15] but wild trout streams are still available for trout fishing. According to the trout angler survey, fishing dates were spread out over the year although more anglers took a trip over summer than other seasons. Thus, it is assumed that entire year is a fishing season and every week is a single trip occasion.[16] Fifty two weeks were used as the total number of occasions available for the season to calculate the trout angler's welfare loss. The trout angler's mean yearly welfare loss ranged from $285 to $2692 according to scenarios (Table IV). However, these values are only illustrative because of the necessary assumptions on trip occasions per season.

6. Conclusion

Angler's expected welfare loss from the trout habitat loss by global warming varied from $5.63 to $53.18 for per angler per trip occasion depending on the scenarios employed in the Southern Appalachian mountains and these figures correspond to 2 to 20% of the angler's consumer surplus. Per angler mean welfare loss approximations for the entire year ranged from $285 to $2692. Mean yearly welfare loss for the entire population can be expanded using the total number of license holders in 1996 fiscal year (217239 anglers), which varied from 61 to 584 million in 1995 dollars. However, these estimated welfare figures from the model are only indicative of the value of potential effects and may not be appropriate to be used to inform policy makers without further research.

To complete an economic assessment of climate change on human welfare through the effects on ecosystems, it is necessary to utilize the best information available regarding future climate projection and ecological assessment. A difficulty with this process arises from the uncertainties involved in each component of assessment. There are still debates on global warming itself among the scientists. Many climate scientists seem to have a lack of confidence in their quantitative projections on temperature changes in the next century. Ecologists investigate impacts of global warming on ecosystems based on a chosen climate scenario. An issue here is then whether human welfare estimates from the economic assessment are reliable or even meaningful considering the uncertainties compounded throughout the assessment.

It is important to note that a purpose of this economic exercise was to illustrate an economic model, which can be applied to estimate potential global warming effects on human welfare at a regional level rather than to provide the definite figures of trout angler's welfare loss due to global warming. The accuracy of the welfare estimates depends on, among other things, the accuracy of the climate change and trout habitat loss assessments that are available. This should continue to evolve and become more detailed.

Another difficulty in the analysis of global warming is the problem of time discounting since the research involves a long time horizon. Angler's welfare loss estimates reported in Table IV potentially will occur many years in the future. However, selecting a time discount rate (i.e., real interest rate to convert future values to current values) has been a controversial issue among researchers. A wide range of time discount rates have been used including the U.S. Office of Management and Budget real discount rate of 10%, the Congressional Budget Office real discount rate of 2%, and even a zero discount rate. While this complexity is acknowledged, it is not the purpose of this research to resolve this issue. Rather this research demonstrates the potential of using non-market evaluation techniques as part of global warming research.

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Notes

[1] This term refers to the heat-trapping effects of rising atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs), and nitrous oxide (NO). The main sources of these greenhouse gases are deforestation, the burning of fossil fuels, and other human economic activities.

[2] GCMs are dynamic models that simulate the physical processes of the atmosphere and oceans in order to estimate global climate under different conditions such as doubling of atmospheric carbon concentrations. Approximately ten research centers worldwide have developed GCMs; in some cases, they were originally designed for weather forecasting.

[3] Examples regarding the economic assessment model of the overall impacts of global warming are Nordhaus (1991) and Cline (1992).

[4] One of the most popularly used GCMs, designed at the Goddard Institute for Space Studies.

[5] The Delphi survey procedure attempts to gather current scientific thinking by surveying experts in the interested field. For this study, the survey panel consisted of 50 experts in coldwater fishery management, coldwater fishery biology, and aquatic ecology. A global warming scenario with a 4.6 °C increase in mean monthly air temperature and 25% reduction in overall summer stream-water levels based on the GISS projection for the Southern Appalachian region was given to panel members. Given this scenario, the survey participants were asked their opinions regarding the potential effects of global warming on groundwater and stream temperature, the oxygen content of streamwater, the extent of trout habitat ranges, mean individual trout size, and total regional number of trout.

[6] The reductions for brown and rainbow trout were forecast to be larger than for brook trout because panel members assumed that stream obstructions would limit the movement of the former species to the headwaters.

[7] In recreation economics literature, random utility models are also referred as the discrete choice model or multinomial (or nested multinomial) logit models. The RUMs are well established in the recreation demand literature. For some applications, see Bockstael et al. (1987, 1989); Milon (1988); Morey et al. (1991, 1993); Parsons and Needelman (1992); Parsons and Kealy (1992); Feather (1994); Kaoru et al. (1995); and Parsons and Hauber (1995).

[8] This is referred to as a nesting structure in the nested logit model. Nesting refers to a decision tree based on the individual's decision process for a trip. A researcher designs a nesting structure according to the individual's expected decision process but it is also true that nesting construction relies on the researcher's own judgement. Therefore, nesting could be anything as long as it explains one's decision process logically. From an econometric viewpoint, the nesting structure depends on the pattern of correlation among the error terms in the random utilities rather than sequential decision making.

[9] All the notation in this section is written for an individual and a single occasion. Subscripts for individual and occasion are omitted for simplicity.

[10] Note that Equation (1) is reduced to $U_n = \gamma Z_n + \varepsilon_n$ for the no-trip option. The presence of Z_n in both this Equation and Equation (1) allows the utility level to be influenced by characteristics of the individual. In the estimation, only differences in utility levels between fishing and non-fishing can be identified, so Z_n is only included in non-fishing equation.

[11] IIA property assumes that the odds of choosing one site over another remains same no matter what happens in the remainder of the choice set (Freeman III, 1993). This assumption can be easily violated in a recreation demand study. For example, suppose there are two alternatives – Lake A and Beach B – to choose from for swimming. Suppose the probability of choosing Lake A or Beach B is one-half for each so that the odds of choosing Lake A over Beach B is one. Suppose Beach C, which is a perfect substitute for Beach B, is introduced. Then the probability of choosing Lake A is likely to remain the same as before since the characteristics of lake are quite different from the those of beach but the probability of choosing Beach B or C would be reduced to one-fourth for each. However, the IIA property of the multinomial logit model forces the odds of choosing Lake A over Beach B to still equal one. This means that the probability of choosing Lake A has fallen to one-third. Therefore, when there are obvious possibilities of substitution among recreation sites, the IIA assumption is clearly violated.

[12] Welfare measurement with the random utility model described here is attributable to Hanemann (1982).

[13] Hanemann (1982) points out that income and price should enter the indirect utility function as $(y_k - p_{ik})$ since income does not vary over alternatives. So, the estimated coefficient on price may be used as the coefficient on income with an opposite sign for calculating CV.

[14] Detailed information on this survey is available from the first author.

[15] Current stocking practice in North Carolina is operated at least once a month March through June by North Carolina Wildlife Resources Commission (NCWRC).

[16] Each day can be treated as a single occasion. However, it is less likely that each angler takes more than 50 trips per year so each week is used for a single occasion instead each day.

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