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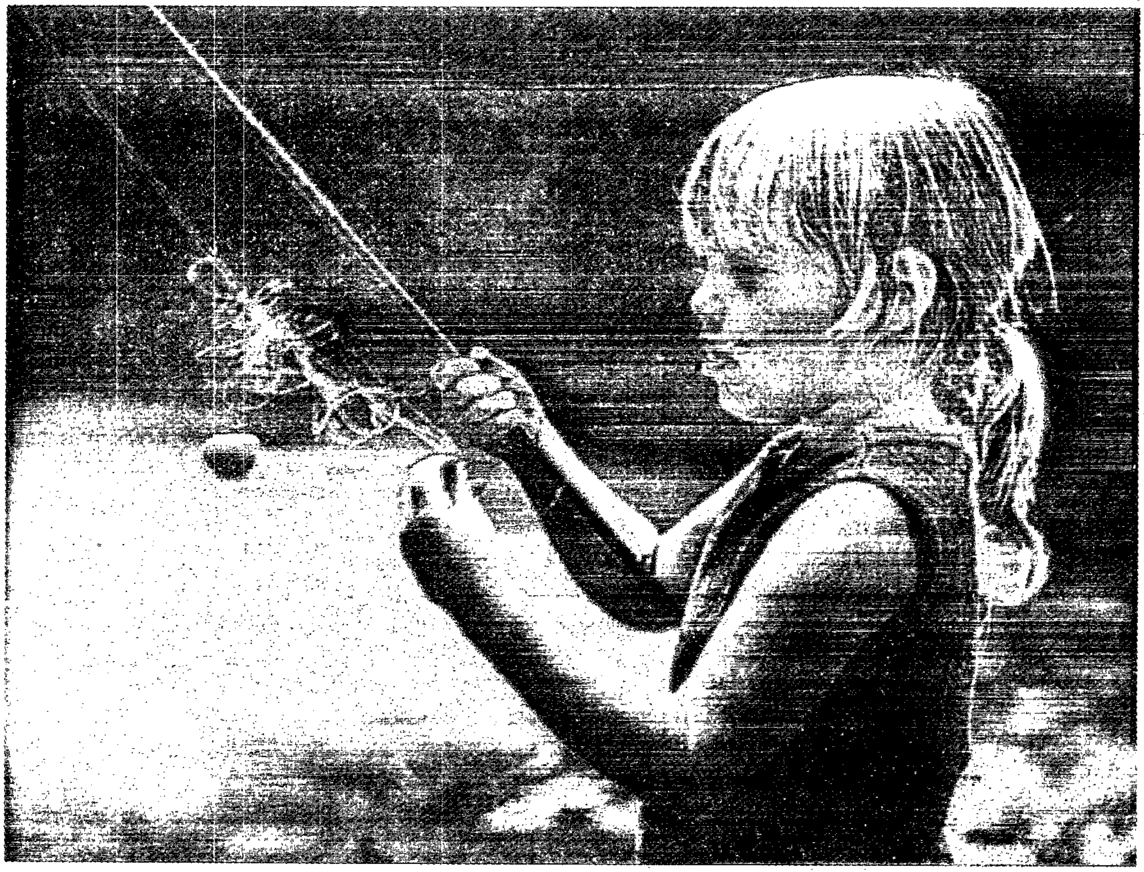
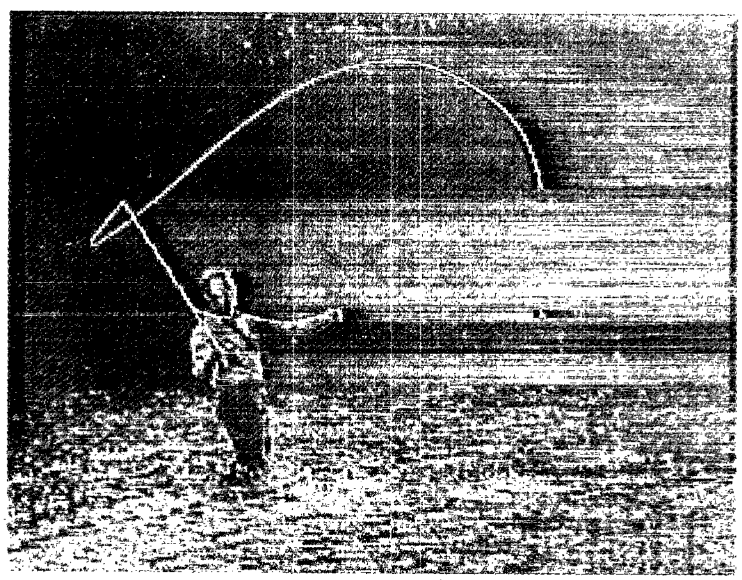
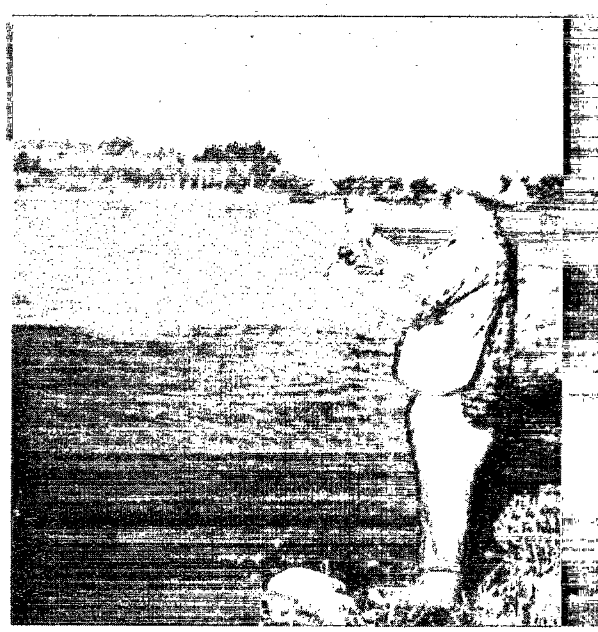
Ecological Impacts From Climate Change: An Economic Analysis Of Freshwater Recreational Fishing







Ecological Impacts From Climate Change:
An Economic Analysis of Freshwater Recreational Fishing

A Report Prepared for

The United States Environmental Protection Agency
Office of Policy, Planning and Evaluation
Climate Change Division
Adaptation Branch

EPA-230-R-95-004

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Ecological Impacts From Climate Change:
An Economic Analysis of Freshwater Recreational Fishing

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Photo Credits - Cover Page

Elizabeth Joy: NPS (Fly fisherman)
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ACKNOWLEDGEMENTS

The contributions of several people made many things possible in this report that otherwise would have been well beyond our budget. The authors would like to single out a few individuals whose help was particularly valuable.

Dr. Joel Scheraga, Chief of EPA's Adaptation Branch, initiated the project that led to this report and has continually kept this study focused on issues that are important to current policymaking. Ms. Susan Herrod, also of EPA's Adaptation Branch, served as the project manager. She kept the project on track at critical junctures and, more than any other reviewer, closely scrutinized our calculations for consistency and accuracy.

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Finally, we would like to acknowledge the key technical input of three individuals. Special thanks go to Dr. John Eaton, of EPA's Environmental Research Laboratory in Duluth, Minnesota, for sharing the results of on-going research on thermal tolerances of freshwater fish and also for serving as an external reviewer, and to Mr. Jim Wallis, of IBM Research, for loaning us precipitation and temperature data in a readily accessible form. Their contributions were central to our analytical framework. We also relied on Mr. Vijay Narayanan, of Technical Resources International, who provided sound technical advice on the use of climate change estimates from general circulation models.

PREFACE

Ecosystem functions and the downstream services they provide may be significantly affected by climate change. The rate and magnitude of potential losses of ecosystem-derived services is a concern to the global community since such losses would negatively affect our welfare and the welfare of future generations. In response to these concerns, the Climate Change Division of the U.S. Environmental Protection Agency (EPA) initiated a scoping study in order to understand the feasibility of assessing these types of impacts, and to gain a better understanding of the extent and geographic distribution of the impacts. The scoping study identified recreational fishing as a feasible service for which damages could be estimated, and as a service with significant economic value that may be at risk from climate change. Based on the findings of the scoping study, EPA conducted further analyses to estimate the potential economic losses to recreational fishing for the entire United States. This report provides the results of these analyses.

The study makes use of extensive work on thermal habitats for various fish species and data from almost one thousand gauging stations and nearby meteorological stations. This information was combined with projections of climate change from four equilibrium general circulation models (GCMs) and one transient GCM to predict present-day and future thermal conditions. A national model of recreational fishing provided estimates of changes in the characteristics of recreational fishing due to climate-induced changes in fish habitat. The results of this analysis support the possibility that substantial damages could result from climate-induced losses of cold and cool water fishing opportunities.

The work described in this report represents one of the first efforts to establish a framework that integrates thermal and economic modeling in order to estimate the impacts to freshwater fish and the socio-economic implications of these physical impacts. This work also represents one of the first attempts to estimate *national* economic damages to recreational fishing from climate change. Because EPA's goal was to produce a national assessment, a simplified approach is taken for linking climate induced ecosystem changes and changes in recreational fishing behavior. Complex relationships, such as reduced productivity and the translation of fish survival into changes in recreational fishing behavior, or characteristics of an array of alternative fishing opportunities available around the country to entire populations of potential anglers, are not considered in this study. Instead of a highly site specific approach, this study focuses on a characterization of fishing opportunities at a higher level of aggregation, and on the characteristics of the anglers themselves.

This study was conducted for the Environmental Protection Agency by Abt Associates, under subcontract to Technical Resources International Incorporated. Before producing the final report, reviews were solicited from EPA staff and experts outside the agency. Their comments are gratefully acknowledged and have been addressed in preparing this final report.

Susan Herrod
Project Manager
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EXECUTIVE SUMMARY

As greenhouse gases accumulate in the atmosphere, the climate will be altered. These changes will consist of rising temperatures, changes in precipitation, and changes in other weather patterns. Ecological processes and ecosystem services are likely to be affected, although determining the subsequent effects on human welfare is often difficult. A dearth of information exists on the linkages from changes in the climate to changes in ecosystems to changes in services valued by humans. One area in which there are likely to be risks from climate change, and where there is enough information to develop estimates of physical impacts and effects on human welfare is fishing. Recreational fishing is both a popular activity in the United States, as exhibited by the millions of Americans who participate annually, and has been the subject of extensive studies, including research on fish tolerances and the potential impacts of climate change on species survival. This study focuses on freshwater fishing in rivers and streams as a starting point for estimating potential impacts to recreational fishing from climate change.

The findings of this report fall into two categories: projected physical impacts resulting from climate change, and the economic value of those impacts. There are fairly substantial physical losses predicted under all of the selected climate scenarios:

- Losses of cold and cool water habitat range from almost 1.7 million acres to 2.3 million acres by about 2060. These acres translate into a complete loss of available cold or cool water fishing in eight to ten states, and a fifty percent loss in eleven to sixteen additional states.
- By the year 2100, ten states loose *all* cold and cool water opportunities, and another 17 loose over 50 percent.
- Cold water guild losses occur throughout their entire range, whereas cool water guild losses are concentrated in the southern sections of their habitable range.
- Species losses tend to be greatest for Brook Trout and somewhat less for Brown Trout, Rainbow Trout and Cutthroat Trout. Of the cool water species, Walleye suffer some loss, primarily in the southern states.

Economic losses are partially offset by the opportunity for anglers to fish in lakes and impoundments, or to turn to other types of fishing (cool, warm, and rough):

- Annual damages of $95 million and $85 million (1991$) are projected using two equilibrium GCM models, with two other models projecting annual benefits of about $80 million each. The results depend on whether gains in cool and warm water fishing will more than offset losses in cold water fishing.
- The GFDL transient 2050 scenario produces the largest welfare losses of the scenarios considered. Annual losses are projected to be $320 million.
- The transient 2100 scenario predicts cold water acreage losses twice as large as those losses predicted by 2050, but the losses are offset slightly by gains in cool, warm and rough acres, resulting in an annual loss of $266 million.
- Analyses conducted to test assumptions and modeling methods reveal that results are most sensitive to the model's treatment of cold water acreage substitution, and to the designation of fish habitat. When most of the alternative modeling methods are employed, or assumptions

relaxed, estimated damages increase substantially, providing evidence of the conservative approach taken in estimating potential damages to recreational fishing from climate change.

The first step in this study was to conduct thermal modeling to estimate the effects of temperature changes on habitat conditions within different geographic areas, and the subsequent effect on the ranges of fish species. This was done by using data for air temperatures at different climatological stations to estimate baseline water temperatures, and then simulating the effect of climate change on baseline air and water temperatures to determine changes to the ranges of fish habitat. The effect of climate change was simulated using temperature increases provided by transient and equilibrium General Circulation Models (GCMs). The most thermally tolerant species in each guild was used as the indicator of whether that guild could survive at each location.

For the second step, the Vaughan and Russell model was used to project changes in recreational fishing behavior based on measures of habitat changes estimated by the thermal model. The model predicted changes in total days spent fishing for recreation, by classes of fish (cold, warm/cool, rough), expressed as a function of changes in fishable acreage for the different classes. To calculate the lost fishing opportunities, the assumption was made that every species in the entire guild must disappear in order for an opportunity to be lost. This assumption is likely to have produced conservative estimates of the losses. Using values per day spent fishing for each class of fish, the annual damages for recreational fishing were calculated.

The thermal modeling predicted significant losses of cold water fish. Losses were generally greatest in the southern border of a species' natural range, where baseline temperatures were closest to thermal tolerances. Cold water species were most affected, but significant losses were also predicted for the cool water guild and for individual members of warm water and rough guilds (e.g., crappie, rock bass, smallmouth bass and white sucker).

Losses of cold and cool water acres ranged from almost 1.7 million to 2.3 million (GFDL and UKMO, respectively). The distribution of these acres geographically represent a loss of available cold or cool water fishing in eight to ten states, and a fifty percent loss in eleven to sixteen additional states, depending on the GCM equilbrium scenario. For most of the scenarios, cold water guild losses occurred throughout their entire range, whereas cool water guild losses were concentrated in the southern sections of their habitable range. Species losses tended to be greatest for Brook Trout and somewhat less for Brown Trout, Rainbow Trout and Cutthroat Trout. Of the cool water species, Walleye suffered some loss, primarily in the southern states. The transient GFDL scenario produced similar results to equilibrium scenarios for the year 2050. However, by the year 2100, losses increased. Ten states lost *all* cold and cool water opportunities, and another 17 lost over 50 percent. Sixteen states lost all brook trout. Brown trout was lost in 2 states and reduced by over 50 percent in another 15 states. Rainbow trout was lost in four states, and Chum and Pink Salmon were lost in three states. The cool water species most affected was Walleye, with four states loosing the species completely.

Although projected losses of cold water fishing opportunities resulting from climate change are fairly significant when considered in isolation, the economic losses may be partially offset by the opportunity for anglers to fish in lakes and impoundments. These sources of fishing opportunities will be less affected by climate change. The losses may also be offset by anglers turning to other types of fishing (cool, warm, and rough). Since the thermal modeling has not adequately addressed changes in habitability conditions for lakes and impoundments, this study assumes that no change occurs in the fishing opportunities there. Thus, the economic results should be viewed as primarily illustrative of how the physical impacts predicted by the thermal modeling might be translated into welfare effects, given modeling constraints and assumptions, and the fact that results are not adjusted to a common year.

The changes in fishing opportunity due to climate change produced mixed results for the equilibrium scenarios. Two scenarios resulted in estimated annual damages of $95 million and $85 million (1991$). However, in the remaining two scenarios, gains in cool and warm water fishing offset losses in cold water fishing, resulting in annual benefits of about $80 million each. When specification of fishing day values were altered to make cool and warm water fishing day values equal, (i.e., the gains in cool water fishing days estimated by these models are worth less), three of the four scenarios produced net welfare losses, with only one scenario producing a gain.

The GFDL transient 2050 scenario produced the largest welfare losses of the scenarios considered ($320 million annually). Unlike the equilibrium GCM results, this is primarily due to the loss of *cool water* acreage. The transient 2100 scenario produced similar results: the cold water acreage losses were twice as large, but were offset by gains in cool, warm and rough acres, resulting in an annual loss of $266 million. Using the alternative specification of equal values for cool and warm water fishing days reversed this trend. The net damages in the 2050 scenario dropped by one-fourth, but the net damages estimated for the 2100 scenario increased slightly to $286 million annually.

Because these results represent a series of conservative choices and assumptions, evaluations were conducted using valid alternative climate, ecological and economic assumptions and modeling methods. When alternative modeling methods were employed, or assumptions relaxed, estimated damages increased substantially. More specifically, for all of the equilibrium model scenarios, the majority of the largest relative changes were associated with modeling assumptions that increase estimated damages.

The areas examined were fishing-day values, climate sensitivity and emissions scenarios, fish thermal tolerances, fish habitat designations, warm-water fishing behavior, cold-water substitutability, and runoff. Results were most sensitive to the model's treatment of cold water acreage substitution, and to the designation of fish habitat. Following these were the climate and emissions scenario and the fish thermal tolerance specifications.

For cold water acreage substitution, instead of assuming that the loss of cold water habitat could be offset by increases in opportunities for other types of fishing, the analysis assumed that the loss of cold water habitat could not be offset - the loss was complete. This modeling change increased damages, which indicates that the degree to which losses in cold water fishing can be offset by other types of fishing is a critical determinant of the magnitude of damages estimated for recreational fishing.

The designation of fish habitat was altered to employ a wider screen to designate fish habitat by state. This change caused an increase in the number of best-use cool- and warm-water acres in the baseline model. "Best-use" is defined as the preferred type of fishing a given water body will support. For this analysis, the assumption was made that anglers prefer cold-water fishing to warm-water fishing and both of these to rough fishing. The result was greater damages in the wide-screen scenario for all equilibrium climate scenarios. This is because the shifts in best-use cool-water acres to warm-water acres were larger than the shifts resulting from the narrow scenario, and the value associated with the loss of cool-water fishing days outweighed that of the gain in warm-water fishing days. Damages increased by at least a factor of five for the OSU and UKMO climate scenarios. The GFDL and GISS model scenarios reversed from projected benefits of $80 and $91 million respectively under the primary specification to damages of $443 million and $451 million under the wide screen designation. For both transient scenarios, the wide screen specification yielded higher losses in best-use cold acreage relative to the narrow screen specification, but the effect on value was a net increase (benefit) because the wide screen had more initial warm-water acreage, making warm-water acreage a better substitute for cool and cold water acreage than it was under the narrow screen. This lead to more benefits as the temperature increased.

Analysis of climate and emission assumptions showed that for *all* scenarios with high temperature increases, total damages were projected. The annual damages ranged from $131 million in GISS to $751 million in UKMO. For scenarios with low temperature increases, total benefits were predicted in all scenarios. The estimated benefits ranged from $36 million (GISS) to $395 million (GFDL). The high temperature transient scenarios resulted in projected damages. However, the low temperature increase scenarios produced mixed results. The GFDL transient (2050) scenario produced damages and the GFDL transient (2100) scenario produced benefits.

Finally, the results of the analysis examining the potential effect of including changes in runoff illustrate that runoff could have a significant effect on economic losses in recreational fishing and should be considered further. The analysis employed simplifying assumptions about volume of annual runoff, potential runoff changes, seasonal variations in runoff changes, marginal values per acre-foot lost, and runoff depth. The results were an estimated loss of between $4 million and $1 billion annually, illustrating that climate-induced changes in runoff alone could lead to significant economic losses in recreational fishing.

Despite mixed results, the analysis in this report supports the possibility that substantial damages could be induced by climate change. The results provide useful guidance for further research and site-specific analyses. Where damages are predicted, they range from $85 million to $320 million annually for the primary modeling specification. These damages only represent losses to recreational fishing in freshwater rivers and streams. Potential gains (benefits) are also not ruled out in this analysis. However, in order to produce benefits, one has to believe that warm water fishing opportunities will expand when cold water habitat is reduced.

The sensitivity analyses conducted on the thermal and economic assumptions made in the recreational fishing analysis further support the conclusion that substantial economic damages could occur. For all of the equilibrium models, the largest relative changes are generally associated with modeling assumptions that increase the estimated damages. In other words, if the primary specification had included selected alternative assumptions tested in the sensitivity analyses, estimated damages would be much larger. Additionally, consideration of the effects of temperature alone may drastically underestimate total damages to recreational fishing in freshwater rivers and streams. Some of the factors excluded from this analysis could contribute to much larger projected losses, as illustrated by the runoff analysis.

These conclusions should be considered in light of the fairly substantial uncertainties involved and the limitations described in the report. However, the potential for substantial losses point to the need for conducting further research to address uncertainties, and to learn more about the magnitude of actual damages that could occur from climate change.

1. INTRODUCTION

Ecological systems are likely to be vulnerable to effects that could be posed by climate change in the next one hundred years. Rapid and large changes in temperature and precipitation could alter the fundamental circumstances that determine the viability of aquatic and terrestrial ecosystems and their constituent organisms. Article 2 of the Framework Convention on Climate Change highlights concerns about the magnitude and speed of these changes, citing as its ultimate objective the stabilization of greenhouse gas concentrations at a level to prevent "dangerous anthropogenic interference with the climate system" and stipulating this level "should be achieved within a time frame sufficient to allow ecosystems to adapt naturally" (United Nations General Assembly, 1992).

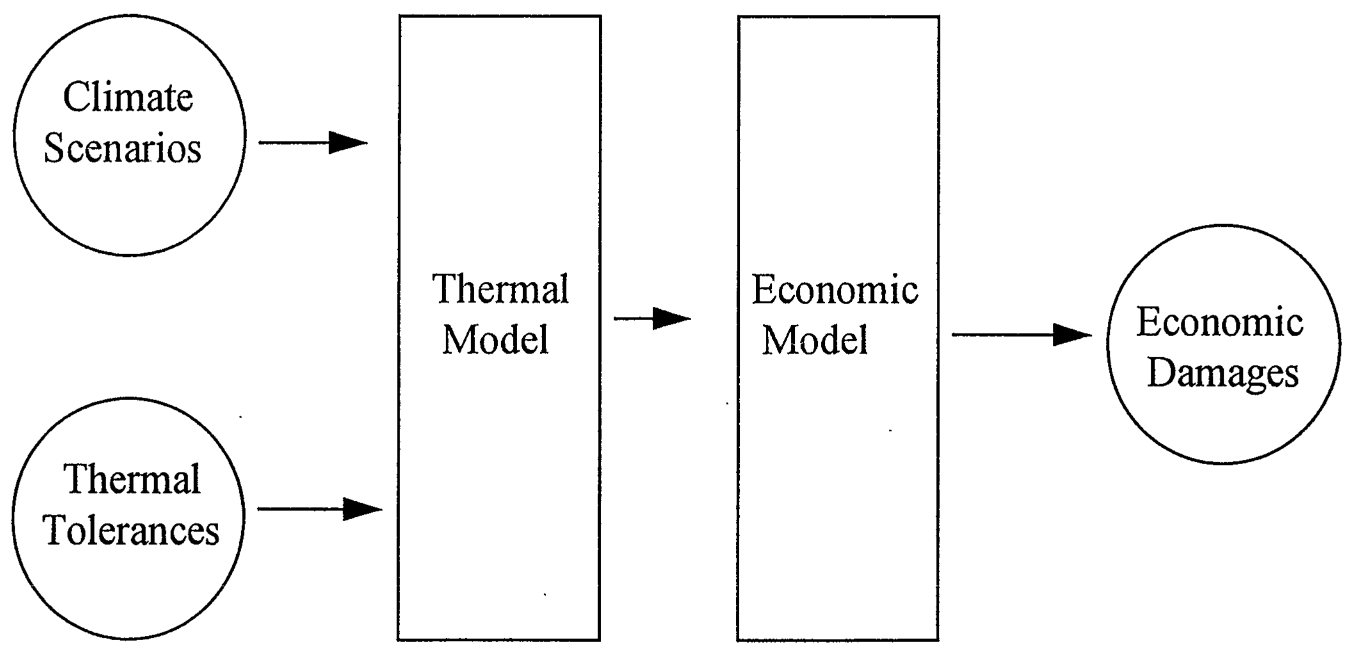
The way that plant and animal species and their associated communities respond to these changes can have significant implications. Three ways generally describe the array of potential responses. Organisms or communities can adapt where they are, they can die and possibly become extinct, or they can migrate to more hospitable environs (Buddemeier, 1991). Of greatest concern would be the extinction of a species. However, even the disappearance of a species from selected individual locations, despite moving or surviving elsewhere, could be a matter of some urgency. Furthermore, others have argued that the transformation of ecosystems induced by climate change will result in a general loss of biodiversity (Markham, et al., 1993).

An earlier report by Abt Associates identified freshwater fish species as one particular element of aquatic ecosystems that could be at risk in the United States (Michaels et al., 1992). The social significance of such a risk is not small. Society has very much at stake when freshwater fish are threatened. In particular, part of what is at stake manifests itself in the recreational fishing activities of millions of Americans each year. Because of this importance, a growing body of empirical studies focused on recreational fishing has been developing over the last twenty-five years. The previous Abt Associates' report concluded that recreational fishing should be a primary focal point in EPA's efforts to build an economic assessment of the impact of climate change on ecological systems, and that the means exist for conducting a preliminary economic assessment of recreational fishing. This report represents the culmination of this preliminary effort and provides its findings.

Two analytical tools were designed and implemented by Abt Associates to conduct the assessment - a thermal model and an economic model. For convenience, each tool is referred to as a "model" but, more importantly, together they constitute one integrated framework. The overall framework is depicted in general terms in Exhibit 1-1. The objective in developing this framework was to generate policy-relevant information from analyses combining physical assessment of climate impacts on ecological systems with economic assessments of the

Exhibit 1-1

Organization of the Analysis: General Overview



significance of these impacts. Physical measures of any substantial risks to freshwater fish could by themselves provide sufficient bases for concern about potential impacts from climate change. Trying to understand the social implications of these physical effects provides a further basis for examining the significance of climate change. Here, social significance is measured in economic terms.

The development of the framework applied in this study is in part attributable to an intentional effort to push the boundaries of existing knowledge in the natural sciences and economics as much as possible. The current body of empirical work in these areas was not developed with climate change in mind and is limited in its capacity to support the types of analyses developed here. Given the limitations of existing knowledge, the results from the aggressive approach taken in this study can be viewed as a possible source of insights on the implications of climate change for recreational freshwater fish but not as a definitive basis for establishing that there are indeed significant threats to these fish and their habitats. A number of uncertainties are acknowledged and explored in this report. Many of them should be the focus of a longer-term research agenda. Still, the results of the current study are presented here with the expectation that certain insights can stand even when major analytical uncertainties are acknowledged.

The remainder of this report has the following organization. The thermal model, introduced and evaluated in Chapter 2, provides a link between the current understanding of temperature changes anticipated in different parts of the U.S. and the resulting reductions in the habitat of different recreational fish species as their thermal tolerances are exceeded. Additional details on the organization of the thermal component are given in Exhibit 1-2. Inputs to the thermal model include temperature changes projected by different general circulation models (GCMs), estimated thermal thresholds for recreational fish species, data characterizing rivers and streams, and definitions of baseline habitat for different guilds of fish (cold-water, cool-water, warm-water, and rough). The thermal model provides estimates of the extent of each guild's habitat in rivers and streams, in the baseline and after climate change. The economic model, adapted from a national model of recreational fishing, uses measures of habitat changes estimated by the thermal model to project changes in the frequency and type of recreational fishing. This report presents estimates of the economic value of these changes. Additional details are provided in Exhibit 1-3. Inputs to the economic model include estimates from the thermal model of guild-specific habitat in rivers and streams, habitat designations for the remainder of freshwater bodies (lakes and impoundments), pertinent data on recreational fishing, and estimates of the value of recreational fishing. The economic model produces estimates of the characteristics of recreational fishing, such as number of days spent by all anglers fishing for cold-water species, which provide the basis for estimating damages from climate change. The economic model and these estimates are presented in Chapter 3. The report closes with an extensive set of model evaluations in Chapter 4. These evaluations consider alternative assumptions in all of three major components of this assessment - the general circulation models that estimate temperature changes, the thermal model, and the economic model. Several appendices provide useful, supplemental information.

Exhibit 1-2

Organization of the Analysis:

Details on Thermal Component

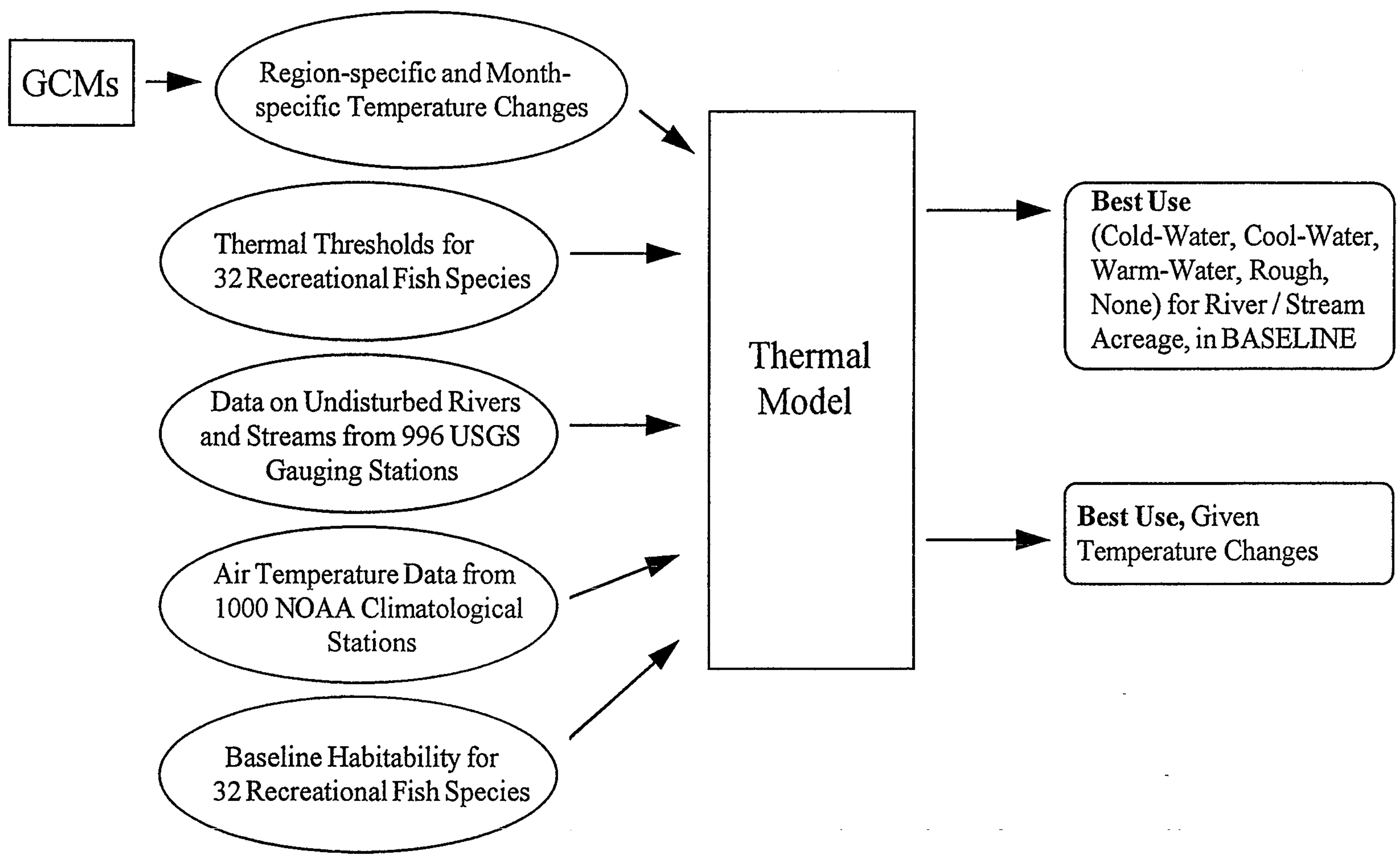
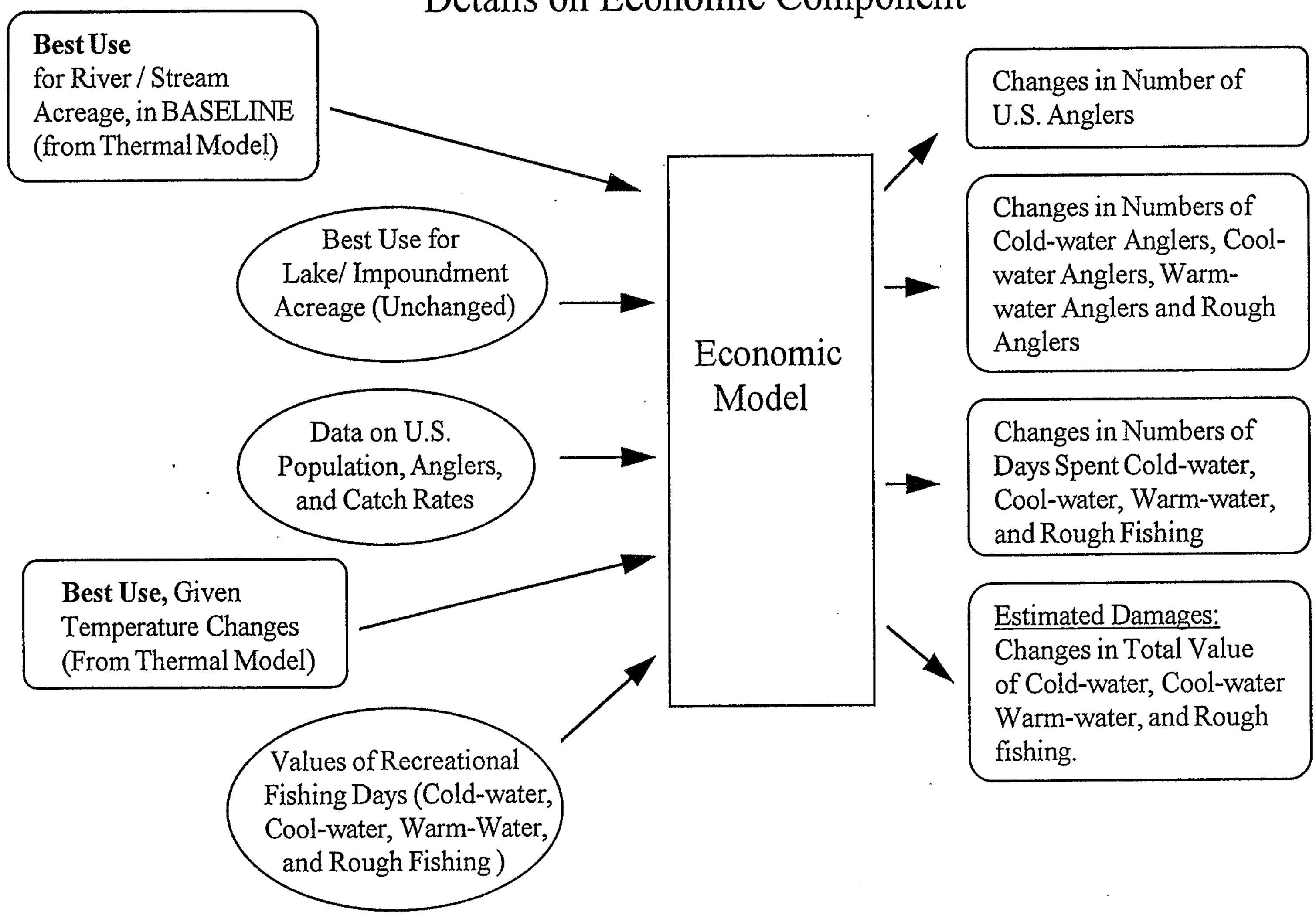


Exhibit 1-3

Organization of the Analysis:

Details on Economic Component



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2. HABITABILITY ASSESSMENT FOR RECREATIONAL FISH IN RIVERS AND STREAMS

Temperature is a very important characteristic of the habitat in which fish live, and the temperature of streams often is closely related to air temperature. Many fish that are adapted to cold- and cool-water conditions are living close to the limits of their thermal tolerances at the present time. These fish could be at risk from global warming in the next century.

Relationships between air temperatures, water temperatures, and ecological effects (including viability of fish) are complex. The relationship between air temperature and water temperatures, for example, depends in part on the physical dimensions of each water body, hydrology, and the extent to which particular water bodies are shaded by riparian vegetation. Vegetation is in turn likely to be influenced by climate. Changes in precipitation would also be likely to affect the relationship between air and water temperatures, and might affect the management of impoundments for water storage. Changes in releases from these impoundments might affect temperature and flow in downstream surface waters. Finally, response by any single species of fish will be influenced by responses of other species to which it is ecologically linked. A rigorous analysis of expected impacts of climate change on fish and recreational fishing would need to consider these and other dimensions of these complex relationships.

Several researchers have used heat balance models and other analytic techniques to predict impacts of climate change for specific regions or water bodies. For example, researchers at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota (in cooperation with the U.S. Environmental Research Laboratory in Duluth, Minnesota), have used heat and oxygen transport models to predict impacts of climate change on 32 fish species in 5 streams and 27 classes of lakes in Minnesota (Stefan, et al., 1992). However, because the goal of this study is to estimate impacts on a national scale with limited time and resources, simpler analytic methods are used to derive rough estimates of impacts at high levels of geographic aggregation.

In this study, estimates of changes in thermal habitability in streams have been obtained for each of the forty-eight contiguous states for each of thirty-two species of fish belonging to cold-, cool-, and warm-water, and rough-fish guilds. The natural and well-established ranges of these species were used to verify the approach; the ranges also were used to prevent the prediction of the occurrence of fish outside their ranges. The long-term viability and the potential for exclusion of species is considered, rather than changes in biomass or yield, because the results are used in determining shifts that might occur from one type of recreational fishery to another. Given the need to estimate impacts at the national level and the fact that this is the first phase of a continuing effort, the study focuses on undisturbed rivers and streams for which good data exist and that are amenable to analysis. Almost a thousand gauging stations and nearby meteorological stations and the results from four equilibrium global circulation models (GCMs) and one transient GCM, run for four scenarios of emissions of greenhouse gases, were used to predict present-day and future thermal conditions.

2.1 SAMPLE SITES

The basic approach for the analysis is patterned after Vaughan and Russell (1982), in which the effects of changed conditions within a representative sample of surface water locations are scaled upwards to derive estimates for effects on fish or recreational fishing over a broad geographical area. Ideally, a large base of high-quality data would be available to describe for each sample location:

- baseline populations of key fish species,
- baseline water temperatures (sampled daily over an extended period of time), and
- baseline air temperatures (sampled daily over a matching time period).

Unfortunately, a national base of such linked data has not been assembled to date. For this analysis, a database assembled by Wallis et al., (1990) for the purpose of studying climatological change and verifying output from global circulation models was used instead. For each of 996 USGS gauging stations, these data contain reports of daily and monthly stream flow, state, latitude and longitude, elevation, size of watershed, and a description of the station's location. To facilitate analysis of climate-related trends in the hydrologic regime, the Wallis team chose stations as free as possible from regulation and with data as free as possible from missing observations. The stream flow stations included in their set are stations with at least 40 years of daily record from streams categorized as Class I (no upstream diversions or regulation) or Class II (minimal upstream diversions and regulation). The 48 contiguous states are all represented in the set, though the East and Northwest have higher density of stations than the Southwest. Exhibit 2-1 shows how these stations are distributed across the U.S. To derive estimates of water temperatures, a matching set of data for air temperatures from about 1000 NOAA climatological stations was used (Wallis et al., 1990). CD-ROM versions of both data sets were obtained for this study.

2.1.1 Assigning Fishable Acres to Representative Locations

As will be discussed in the next chapter, the chosen methods for relating the availability of freshwater fish to fishing behavior and value require estimates for the number of fishable acres of surface water in which each guild of fish (i.e., cold-water, cool-water, warm-water, or "rough") is present in each state. To derive such estimates for each sample station requires an estimate for the number of fishable acres represented by that station, and an appropriate weight for each station to scale the results to the state (and ultimately to the national) level. First, the number of fishable acres of rivers and streams available in each state are estimated. These estimates are derived from values reported in Vaughan and Russell (1982). As shown in Exhibit 2-2 Vaughan and Russell's totals represent total fishable acres of surface water in each state, and must be adjusted to reflect only those fishable acres available in the undisturbed rivers or streams studied by Wallis, et al. From data compiled by the U.S. Fish and Wildlife Service for the 1985 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, the fraction of reported fishing days in each state attributable to rivers and streams was determined. This fraction for each state was derived as the number of reported days spent fishing in rivers and streams divided by the total number of reported fishing days and was used to approximate the fraction of fishable acres available in this category of surface waters. Applying this ratio to the total results in the estimates listed in the third column of Exhibit 2-2.

The second step is to apportion these estimates of each state's total fishable acres on rivers and streams among the individual sample locations used in the model. This is done assuming that the total fishable acres available within each state are represented by individual stations in proportion to the area of monitored watershed in the state represented by each station. For example, if the area of the contributing watershed for a particular station represents 5 percent of the total of such areas for all stations in the sample for a given state, that station is used to represent 5 percent of the fishable acres available in rivers and streams in that state.

The median catchment area represented by a station in the set is 294 square miles, varying by region from an average of 103 to 575 square miles. Because of the selection criteria used to assemble the database, these watersheds may be more remote and at higher elevation than average. The effect of this selection might therefore be a downward bias in water temperatures for the sample locations used in our modelling. Such a bias would also reduce predicted temperatures after climate change, and might result in conservative estimates of the effects of climate change. Alternately, extrapolating from thermal damages of undisturbed rivers and streams to managed rivers and streams may contribute an upward bias to the overall estimated damages. Managed rivers and streams encompass impoundments which permit some control of water temperatures through appropriately timed releases. Furthermore, impoundments can provide cold-water species more refuges with suitable temperatures. Although impacts of temperature and runoff-changes on impoundments are currently being investigated in a separate Abt Associates study, the net effect of these biases is unknown.

Exhibit 2-1
Geographic Distribution of Stations

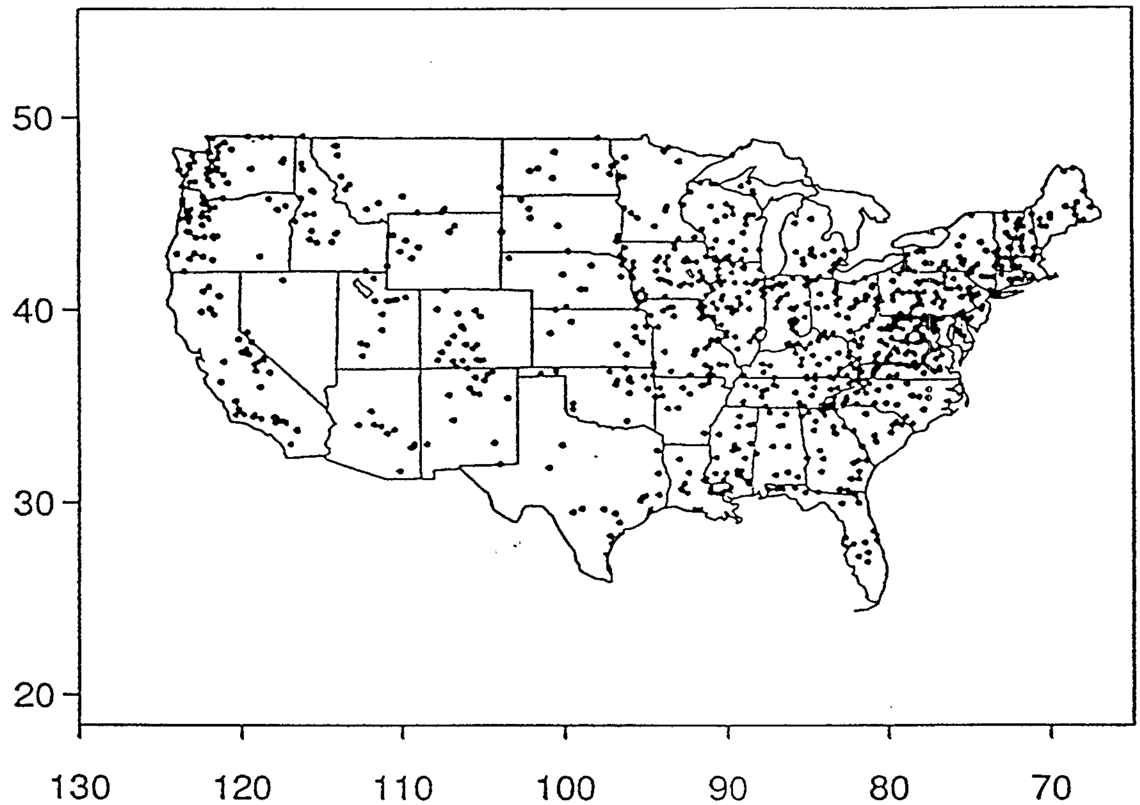


Exhibit 2-2
Fishable Acres of Rivers and Streams by State

State	Total Fishable Acres (thousands)[1]	Rivers and Streams as Percent of Total[2]	Fishable Acres of Rives and Streams (thousands)
Alabama	574	40.2%	231
Arkansas	811	34.3%	278
Arizona	200	19.8%	40
California	863	33.7%	291
Colorado	176	24.4%	43
Connecticut	48	31.9%	15
Delaware	5	23.7%	1
Florida	1,968	20.8%	410
Georgia	625	21.7%	136
Iowa	335	38.5%	129
Idaho	570	42.0%	239
Illinois	371	24.0%	89
Indiana	129	19.0%	24
Kansas	301	19.5%	59
Kentucky	526	25.0%	131
Louisiana	2,215	30.5%	675
Massachusetts	133	26.4%	35
Maryland	151	32.2%	49
Maine	1,638	33.5%	548
Michigan	940	19.8%	186
Minnesota	2,594	11.2%	292
Mississippi	551	21.6%	119
Montana	1,015	42.3%	429
North Carolina	822	28.9%	238

[1]Vaughan, W.J. and C.S. Russell. 1982. Freshwater Recreational Fishing: The National Benefits of Water Pollution Control. Resources for the Future, Washington, D.C.
[2]Data from the 1985 Survey of Fishing, Hunting, and Wildlife-Associated Recreation (U.S. Department of the Interior, U.S. Fish and Wildlife Service, 1988).

Exhibit 2-2 (continued)
Fishable Acres of Rivers and Streams by State

State	Total Fishable Acres (thousands)	Rivers and Streams as Percent of Total[2]	Fishable Acres of Rivers and Streams (thousands)
North Dakota	541	32.4%	176
Nebraska	176	23.6%	42
New Hampshire	197	34.0%	67
New Jersey	119	31.4%	37
New Mexico	135	22.8%	31
Nevada	351	27.0%	95
New York	1,735	36.6%	635
Ohio	241	21.8%	53
Oklahoma	904	13.1%	118
Oregon	592	58.9%	349
Pennsylvania	122	47.8%	58
Rhode Island	NA	22.5%	NA
South Carolina	689	26.0%	179
South Dakota	723	27.1%	196
Tennessee	663	33.4%	221
Texas	1,469	17.2%	253
Utah	372	26.1%	97
Virginia	452	33.6%	152
Vermont	139	38.0%	53
Washington	1,158	33.4%	387
Wisconsin	1,138	24.6%	280
West Virginia	141	64.2%	91
Wyoming	414	33.2%	137
Total	30,737		8,394

[1]Vaughan, W.J. and C.S. Russell. 1982. Freshwater Recreational Fishing; the National Benefits of Water Pollution Control. Resources for the Future, Washington, D.C.
[2]Data from 1985 Survey of Fishing, Hunting, and Wildlife-Associated Recreation (U.S. Department of the Interior, U.S. Fish and Wildlife Service, 1988).

2.1.2 Estimating Water Temperatures

The database of 996 stations used in this study does not contain information for water temperatures (or the presence of fish species) under baseline conditions. Temperatures are therefore predicted for each location as a function of historical records of air temperature at the nearest climate station. Maximum and minimum daily air temperatures are averaged to estimate daily average temperature, with years of data excluded if they contain values flagged as suspect within the data base. Daily average temperatures are then averaged across the 28 years of available data for each climate station to calculate a 28-year average temperature for each calendar date. Finally, since this study focuses on the annual maximum weekly average temperature, as will be explained in the next section, the daily averages are averaged across consecutive 7-day periods to determine weekly average temperatures, and (for reasons to be discussed in Sections 2.2 and 2.3) the maximum of these weekly values is identified for each station. Exhibit 2-3 summarizes results for each state in the U.S., with the lower map displaying maximum weekly average air temperature for the station with the lowest value in each state, and the upper map displaying the maximum weekly average temperature for the station with the highest value. It shows, for example, that maximum weekly average air temperatures for stations in Texas ranged from 27.6-29.4°C. The narrowest range of maximum temperatures is observed in Connecticut (21.5-21.9°) and in Maine, where a single climate station was closest to all flow stations in the sample. The greatest range is observed in California, where maxima range from 19.0-33.6°C.

The best method for relating air to water temperatures would be to use site-specific modelling of heat balance for each water body of interest. Because such analyses are not feasible within the limitations of this project, however, this analysis must rely on less sophisticated methods. Four alternative methods were investigated for this study. Each is examined in turn below.

The simplest analytic option (Method 1), and the one ultimately chosen for this study, is to use unadjusted maximum weekly average air temperatures to represent maximum weekly average water temperature. The magnitude of error introduced by this simplifying step will naturally depend on the relationship between air and water temperatures for the stations modeled in this study. To the extent that extremes of water temperature are moderated by groundwater inflows, for example, maximum weekly average water temperatures are likely to be closer to annual average values (i.e., lower) than maximum weekly average air temperatures (Stefan and Preud'homme, 1993). If maximum water temperatures do in fact tend to be generally lower than corresponding maximum air temperatures for most stations, the method of using unadjusted air temperatures is likely to yield overly high estimates of maximum water temperatures under baseline conditions and therefore to underestimate the natural ranges of cold-water fish species. Because the estimates of impacts from climate change are driven by the warming of surface waters beyond fish species' tolerance limits, an overestimation of baseline temperatures might also lead to overestimation of the impacts of global warming on fish habitat, as true baseline temperatures might not be as close to tolerance limits as those modeled. Moreover, if the amplitude of seasonal swings in water temperature is smaller than the corresponding amplitude for air temperatures, "forcing" of temperatures from global climate change should likewise be damped when modelling effects on surface waters. Conversely, in locations where maximum weekly average water temperatures exceed maximum weekly air temperatures at the nearest climate station, both the impact of climate change will be under-predicted if unadjusted air temperatures are used as a surrogate for water.

Stefan and Preud'homme (1993) have used linear regression to investigate the relationship between air and surface water temperatures for 11 streams in the central U.S. (Mississippi River basin). They found that weekly average water temperatures could be related to weekly average air temperatures for their stations (in aggregate) with the relationship:

$$T_w = A + B T_a \tag{2-1}$$

where:

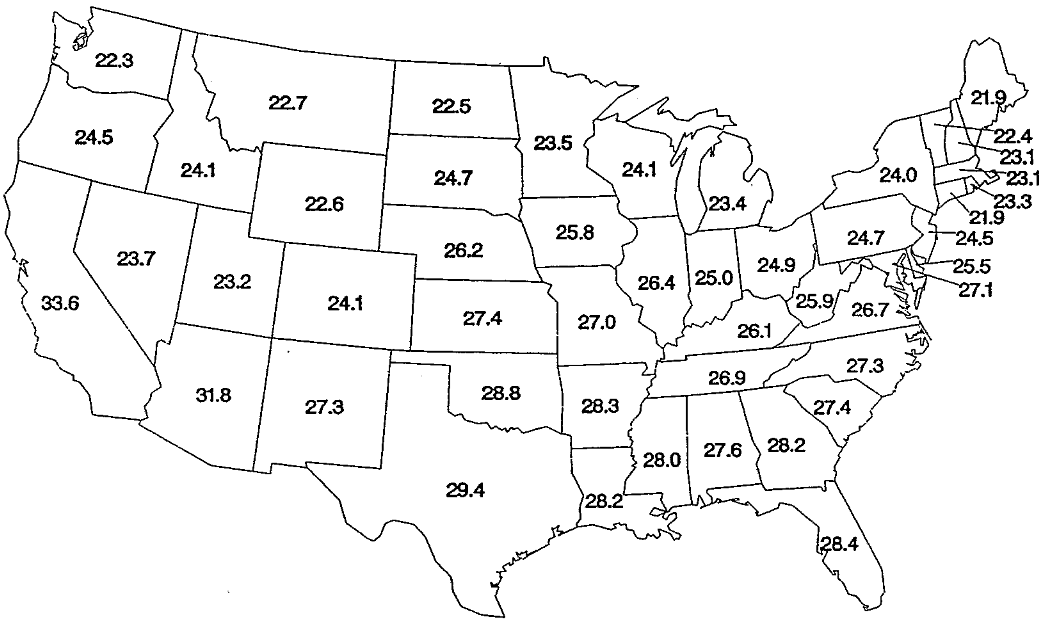
T_w	=	weekly average water temperature (°C),
T_a	=	weekly average air temperature (°C),
A	=	intercept, and
B	=	regression coefficient.

This regression equation provides predictions of weekly average water temperature (T_w) as a function of weekly average air temperature (T_a). Values of B derived from their analysis ranged from 0.669 to 1.026, with seven of the eleven estimated coefficients falling between 0.75 and 1.0. Values of A ranged from 1.40°C to 5.41°C. Standard deviations of measured T_w compared to T_w from the regressions for individual rivers ranged from 0.65°C to 3.17°C, and averaged 1.50°C. The average value of B for the 11 rivers studied was 0.864 with a standard deviation of 0.11, and the average for A was 2.91°C with a standard deviation of 1.43°C. The authors tested water temperatures predicted by these averaged coefficients against actual values to calculate a standard deviation of 2.16°C. They note the improvement achieved by using regression equations established for individual rivers as compared to the averaged result.

One possible method for relating air to water temperatures (Method 2) would be to use Equation 2-1 directly to predict water temperatures for each sample location used in this analysis, but there are two problems with using the equation for that purpose. First, data used in Stefan and Preud'homme's analysis were restricted to the central U.S.; their generalization to other regions and watersheds is questionable. Second, Equation 2-1 adjusts air temperature downwards when calculating water temperatures from air temperatures greater than about 21°C, and upwards for lower air temperatures. For the approximately 25 percent of climate stations used in this analysis for which mean annual air temperatures are lower than 21°C, this relationship would suggest that mean annual water temperatures should exceed mean annual air temperatures. Similarly, approximately 5 percent of the stations report maximum weekly

Exhibit 2-3
Maximum Weekly Average Air Temperature

Highest Maximum per State



Lowest Maximum per State

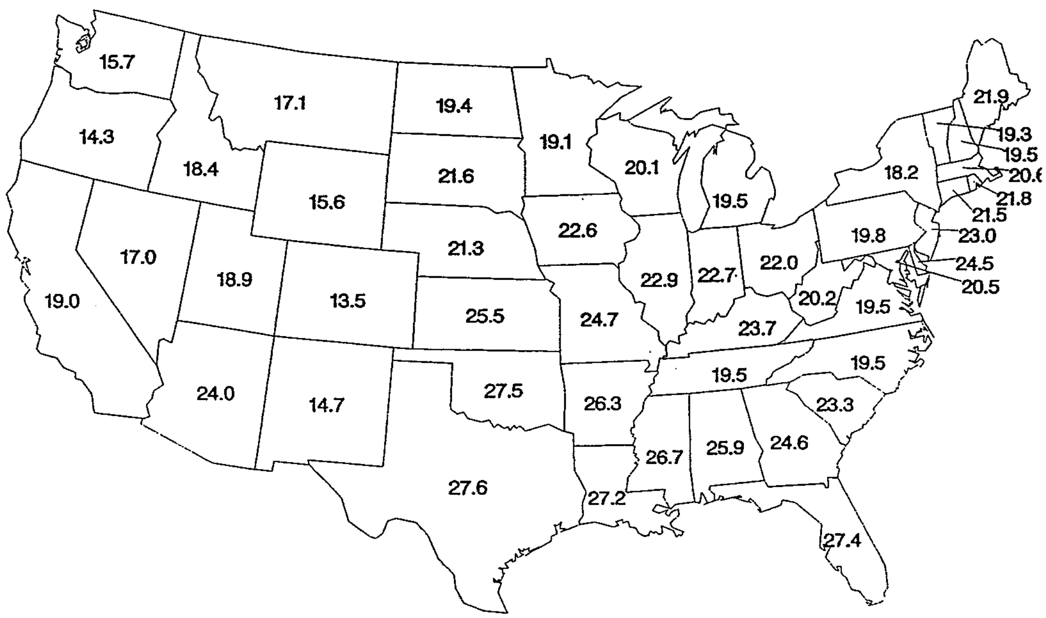
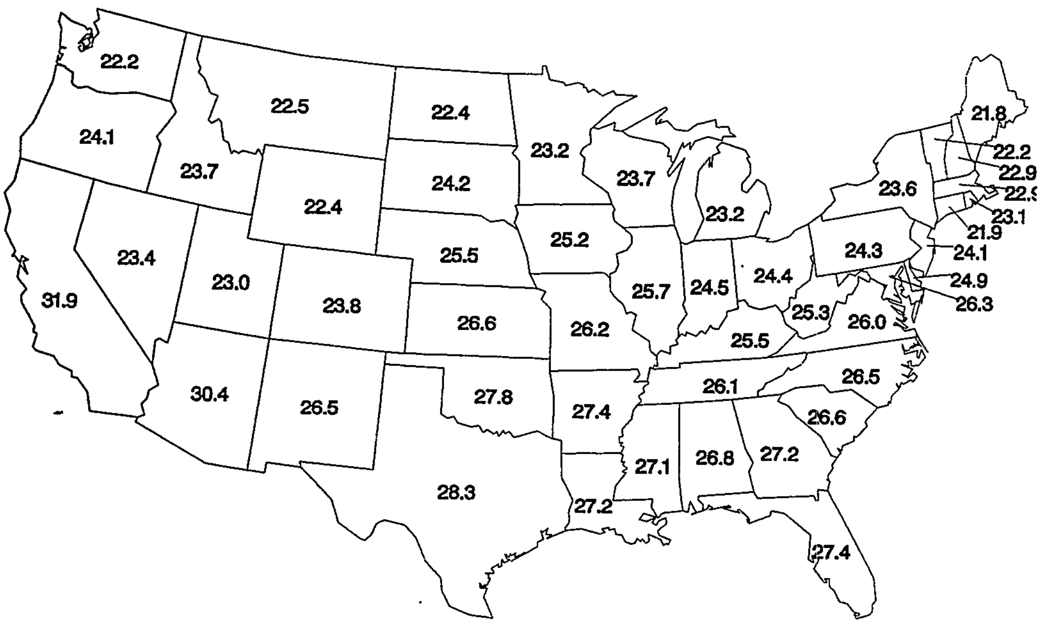
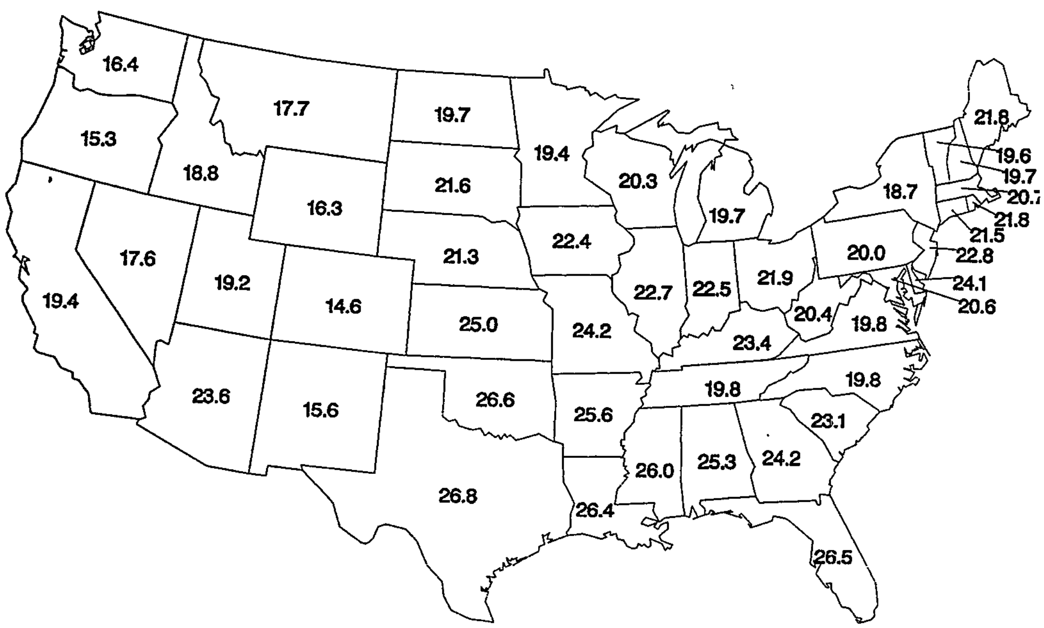


Exhibit 2-4
Maximum Weekly Average Water Temperature
(Method 2)

Highest Maximum per State



Lowest Maximum per State



average air temperatures below 21°C; for those stations, Equation 2-1 would predict maximum water temperatures exceeding air temperatures by up to about 1°C. These systematic upward adjustments of lower temperatures may not be physically justifiable.

Exhibit 2-4 shows water temperatures predicted with Equation 2-1 (where A=2.91°C and B=0.864). As is evident from a comparison of Exhibits 2-3 and 2-4, differences between (unadjusted) air temperatures and water temperature predicted by Equation 2-1 range from a low of about -1°C for the coldest station in New Mexico (13.5°C compared to 14.5°C) to a high of about +1.8°C for the hottest station in California (33.6°C compared to 31.8°C). Further inspection of these exhibits suggests that this difference is equivalent to the temperature change associated with perhaps 200-400 km of latitude.

A third alternative (Method 3) begins by assuming that mean annual water temperatures should generally approximate mean annual air temperatures for natural, undisturbed streams without heat sources or sinks (as suggested by Song et al., 1973). If so, then:

$$T_w = A + B\,T_a$$

and:

$$\bar{T}_w \approx \bar{T}_a$$

imply:

$$A \approx \bar{T}_a\,(1-B)$$

or:

$$T_w \approx \bar{T}_a\,(1-B) + B\,T_a \qquad (2\text{-}2)$$

where:

$\bar{T}_w$	=	annual average water temperature (°C),
$\bar{T}_a$	=	annual average air temperature (°C),
A	=	constant (°C), and
B	=	regression coefficient (dimensionless).

Based on Equation 2-2, this method for predicting maximum water temperatures might use the B=0.864 result from Stephan and Preud'homme (1993) but adjust the constant A in the equation to match mean annual air temperature for each location modelled. The technique would adjust air temperatures downward for all locations, increasing the predicted presence of cold- and cool-water fish guilds in southern states of the U.S. With both Equations 2-1 and 2-2, expected increments to maximum weekly average water temperature (as a consequence of climate change) could be related to increments in maximum weekly average air temperature as:

$$\Delta T_w = 0.864\, \Delta T_a$$

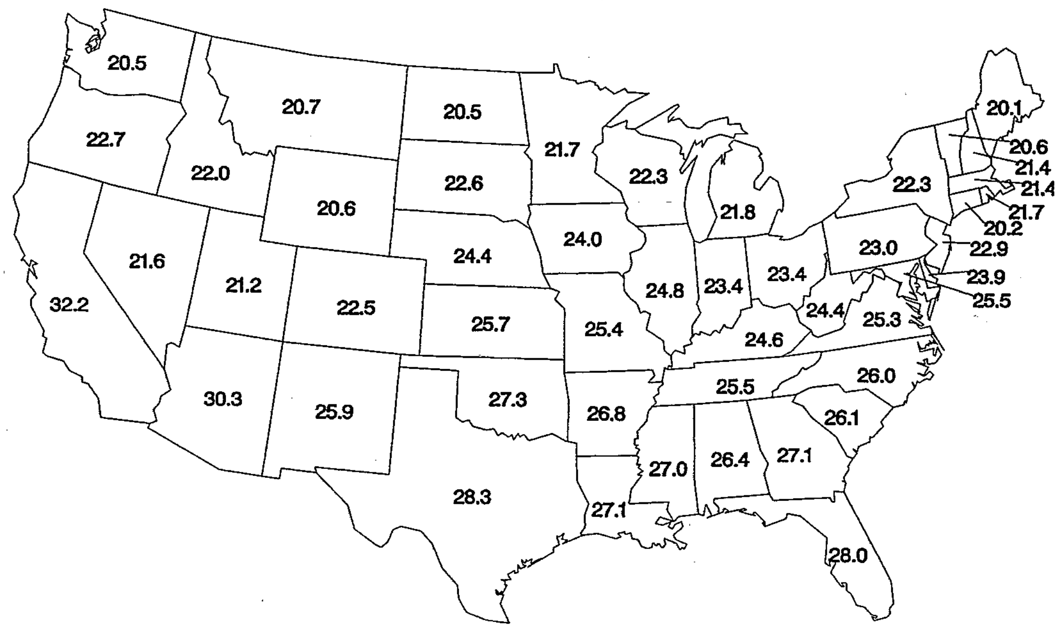
Results are summarized in Exhibit 2-5. As expected, water temperatures predicted by this method are consistently lower than those predicted with Method (1).

As a fourth alternative method (Method 4) for estimating T_w, the STORET data base maintained by the U.S. EPA was accessed to obtain all records of air and water temperatures available for the USGS gauging stations used this study. This source provided 56,840 records of water temperatures for 785 of the 996 stations used for this analysis (an average of 72 records per site). STORET also contained 19,484 records of measurements of air temperatures at these same locations, for those observations containing both air and water data, the ratio of water to air temperature (in °C) was approximately 0.88. A serious limitation of these data, however, is their irregular sampling (generally no more than 1-2 samples per month per station per year, taken at irregularly scheduled times of day and year). For example, more than 94 percent of the samples were taken between the hours of 8 AM and 5 PM; the effect of this bias appears to vary from site to site, depending on the lag between air and water temperatures. Because water temperatures tend to vary significantly by time of day (see for example, Stefan et al., 1993), estimating maximum weekly average temperatures from such constrained data is difficult. Nevertheless, non-linear regression techniques were used in an attempt to adjust each station's data for site-specific time-of-day bias, and a sine function describing seasonal variation in temperature was then fit to the adjusted data for each station. These results were used to estimate maximum weekly average water temperature for those gauging stations with sufficient data. Initial results from these attempts, however, did not produce regression equations with sufficient statistical significance, and this effort was discontinued because of constraints in time and resources.

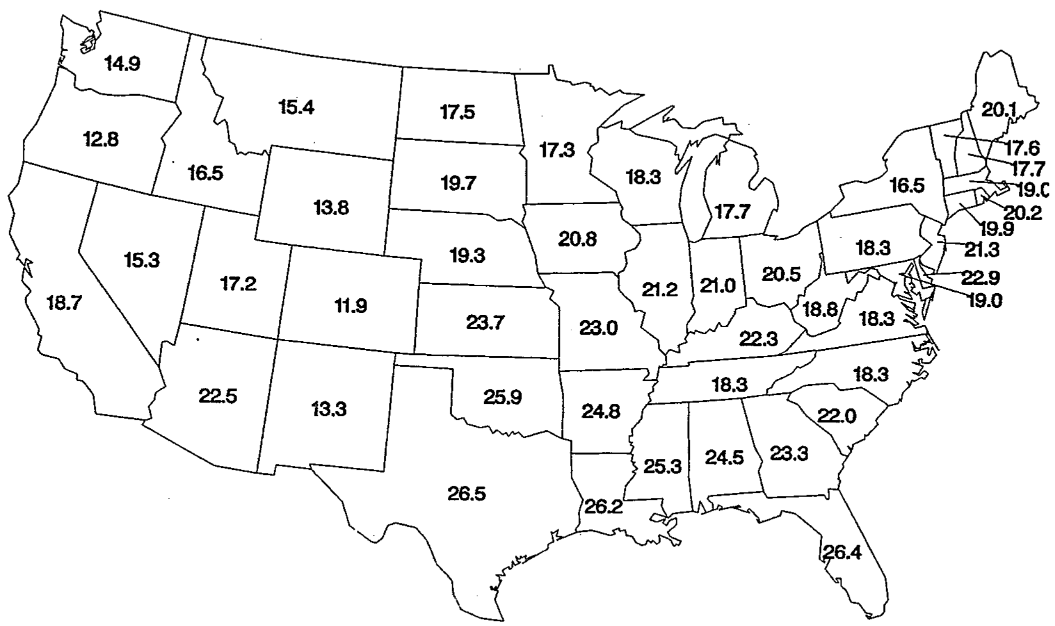
In summary, four methods were tested for predicting water temperatures based on air temperatures. Method (1), the simple assignment of air temperatures to water, is likely to over-predict water temperatures in areas where groundwater inflows are significant. Methods (2) and (3) require questionable application of regression coefficients outside their intended contexts. Method (4) is theoretically preferable but failed for limitations imposed by available data and resources. As will be discussed in Section 2.3.1, Method (1) has been selected for providing "best estimates" of the impacts of climate change, for two reasons. First, its predictions for baseline ranges of fish habitat match reported ranges for the fish species considered about as well as Method (2), and better than Method (3). Second, Methods (2) and (3) require that regression results from Stefan and Preud'homme (1993) be used outside their appropriate context.

Exhibit 2-5
Maximum Weekly Average Water Temperature
(Method 3)

Highest Maximum per State



Lowest Maximum per State



2.2 THERMAL TOLERANCES AND GUILD ASSIGNMENTS FOR FISH SPECIES

To predict impacts of climate change on the species of freshwater fishes present at representative stations, quantitative links must be established between climate and the likely presence of individual species or guilds of freshwater fish. Two general approaches are available for this step. First, coupled data for surface water temperatures and the presence of fish species can be used to determine thermal ranges. With this approach, it is assumed that fish of a particular species cannot survive outside the range of surface water temperatures the species currently inhabits. A second approach uses results from laboratory analyses of thermal tolerances. As the result of several decades of scientific interest in the thermal tolerances of fish, both approaches have been well-developed through previous and ongoing research. Effects such as changes in ecosystems inside and around thermal plumes from cooling water discharges have attracted much scientific attention, and the effects of different temperatures on freshwater fishes have been studied extensively in the laboratory since the 1940s. For many important fishes, researchers have determined acute lethal temperatures at short time intervals, preferred temperatures with respect to acclimation, and the effects of temperature on fish bioenergetics. Others have continued the study of behavioral responses of fish to thermal discharges and the long-term effects of elevated temperature on growth and mortality of certain fish.

Several different indices are commonly used to describe thermal tolerances of fish in laboratory experiments. Values for the following measures are summarized for 32 important species in Exhibit 2-6:

- UILT = Upper Incipient Lethal Temperature. This value is the point of 50 percent mortality for an experimental group that has been acclimated to a certain temperature before being exposed to the experimental temperature for a given exposure period (Hokanson and Beisinger 1989). The lethal temperature generally increases with increasing acclimation temperature, until a maximum is reached, beyond which no increase in UILT is seen. This maximum UILT is listed without an acclimation temperature and called the Ultimate Upper Incipient Lethal Temperature, or UUILT (Fry et al., 1946, in Eaton 1993). Eaton et al., list available UILTs and UUILTs together as Upper Thermal Tolerance Limits (UTTL).

- Short-Term Maximum. This is a calculated criterion based on the upper incipient lethal temperature and is designed to provide a measure of safety for all the organisms. It is calculated by fitting experimental data on a straight line on a semi-logarithmic scale, with exposure time on the logarithmic scale and temperature on the linear scale. The calculated short-term maximum temperature is:

$$T_{short} = \frac{(\log_{10} time_{\min} - a)}{b} - 2^{\circ} C$$

Exhibit 2-6
Comparison of Laboratory and Field-Derived Thermal Tolerance Values

Species	Abbr.	Guild	UTTL4 (C)[1]	Short-term Max. Temp.[2]	UZNG[3]	MWAT -Gro[4]	Lethal Temp.[5]	FTDMS[6]
Black crappie*	BLC	warm	32.5 @ na		30	27	32.5 @ 29	30.6
Bluegill*	BLG	warm	37.3 @ 33, 4d	35	36	32	37.3 @ 32.9 (J)	31.7
Brook trout	BKT	cold	25.3 @ 24, 3.5d	24	21	19	26.6	21.2
Brown bullhead*	BRB	rough	37.5 (ult.), 3.5d				37.5 @ 36 (ult.)	30.9
Brown trout	BNT	cold	25.3 @ 23, 7d		21.1		25.3 (ult.)	23.8
Carp*	CAP	rough	36 @ 34, 2d				35.7 @ 26	30.9
Channel catfish*	CCF	rough	37.8 @ 34, 5d	35	35	32	38 @ 35 (yearlings)	31.1
Chinook salmon	CHS	cold	25.1 (ult.) 8.5d					24.0
Chum salmon	CMS	cold	23.8 (ult.), 6.3d		19.1			19.2
Coho salmon	COS	cold	25 (ult.), 6.3d	24	23	18	25 @ 20 (fry)	23.3
Cutthroat trout	CUT	cold	--					22.8
Flathead catfish*	FCF	rough	--					32.2
Freshwater drum*	FWD	rough	32.8 @ 25-31, 2d					31.4
Gizzard shad*	GIS	warm	36.5 (ult.), 1d				36.5 @ 35	31.4

Species	Abbr.	Guild	UTTL4 (C)[1]	Short-term Max. Temp.[2]	UZNG[3]	MWAT -Gro[4]	Lethal Temp.[5]	FTDMS[6]
Golden shiner*	GOS	warm	34.7 (ult.), 1d				34.7 @ 30	30.1
Green sunfish*	GSF	rough	35.4 (ult.), 2d				34 (field)	30.2
Largemouth bass*	LMB	warm	36.4 @ 30, 1d	34	35.5	32	37.5 (av)	30.6
Mountain whitefish	MWH	cold	--					22.3
Muskellunge	MUE	cool	--				33.3 @ 30 (juv)	28.8
Northern pike	NOP	cool	28.4 @ 18, 7d	30	28	28	33.3 @ 30 (juv)	28.8
Pink salmon	PKS	cold	23.9 (ult.), 4.3d					18.8
Pumpkinseed	PMK	cool	--				24.5@ 25[7]	28.9
Rainbow trout	RBT	cold	26.6 @ 24, 1d	24	23	19	28	23.7
Rock bass	RKB	warm	36 @ 36, 7d				35	28.9
Sauger	SAR	warm	30.4 @ 25.8, 4d			25		30.3
Smallmouth buffalo*	SAB	rough	--					31.5
Smallmouth bass	SMB	warm	35 @ 35, 7d		35	29	35	28.4
Walleye	WAE	cool	34.1 @ 28, na		30			28.9
White bass*	WHB	warm	33.5 @ 25-31, NA		35			31.4
White crappie*	WHC	warm	33 @ na		29.2	28		31.4

Species	Abbr.	Guild	UTTL4 (C)[1]	Short-term Max. Temp.[2]	UZNG[3]	MWAT -Gro[4]	Lethal Temp.[5]	FTDMS[6]
White sucker	WTS	rough	32.4 @ 26.1, na		30.2	28	31.2 @ 25-26	27.2
Yellow perch	YEP	cool	33 @ >30, 7d		32.1	29	30.9 @ 25	29.4

Notes:
All temperatures are in degrees Celsius.
These species' naturalized ranges extend south across the U.S. border.
[1] Upper Thermal Tolerance Limit (Eaton et al., 1993). This limit depends on the acclimation temperature (shown as @T) and exposure time (shown in days).
[2] Short Term Maximum Temperature (U.S. EPA, 1986).
[3] Upper Zero National Growth Temperature (Hokanson & Biesinger, 1989).
[4] Maximum Temperature for Growth (U.S. EPA, 1986)
[5] Lethal Temperature (Leidy & Jenkins, 1977). This limit depends on acclimation temperature (@T) and lifestage.
[6] Fish-Temperature Data Matching System 95th Percentile Value (Eaton et al., 1993).
[7] This value is probably in error in the Leidy & Jenkins (1977) report.

where a and b are calculated from data in Appendix II-C of the National Academy of Sciences Water Quality Criteria (U.S. EPA 1986.)

- Upper Zero Net Growth (UZNG). Under a defined set of experimental conditions (such as unlimited food, good quality water), there is a thermal zone within which the growth rate of a population exceeds its mortality rate, so that the population experiences net growth. The upper limit of this zone is called the Upper Zero Net Growth temperature (Hokanson and Biesinger, 1989).

- Maximum Temperature for Growth (MWAT-Gro). Because growth is such an important temperature-sensitive biological function (second only to reproduction), the growth-limiting temperature has received much scientific attention. One approach to estimating the limiting temperature was to average the optimum temperature for growth (T_{opt}) and the UZNG. Because of the limited availability of UZNG's, the approach adopted by U.S.EPA in Quality Criteria for Water 1986 was to calculate a maximum temperature for growth in terms of the UUILT and the optimum temperature (T_{opt}):

$$MWAT\text{-}Gro = T_{opt} - \frac{(UUILT - T_{opt})}{3}$$

(U.S. EPA 1986).

- Lethal Temperatures (T4). In developing population rate coefficients to use in modelling reservoir ecosystems, a list of optimum or preferred temperatures, lower lethal temperatures, and upper lethal temperatures was assembled for the Chief of Engineers of the U.S. Army. The upper lethal temperatures (T4) are listed along with the acclimation temperature and lifestage of experimentation, and ultimate lethal temperatures are noted (Leidy and Jenkins 1977).

These types of tolerances were often derived in response to specific information needs. In the 1970s, one such priority was to establish scientifically defensible basis for enforceable regulation of thermal discharges. In response, the U.S. EPA Environmental Research Laboratory at Duluth, MN (ERL-D) began a project to verify the laboratory-derived tolerances with field data, which led to the development of a Fish Temperature Data Matching System or FTDMS (Hokanson, et al., 1989). This database matches the observed presence of a fish species in streams and rivers with weekly mean temperatures from geographically linked sites in the continental U.S., creating a "fish/temperature (F/T)" data set for each observation. With continued interest in field-data based tolerances of fish species, especially motivated by concern over climate change, the database has grown. In 1993, it contained 141,208 weekly mean "F/T" observations for 29 species (Eaton et al., 1993). Additional species contribute F/T data to the set, and results from analyses of data for these species have become available since 1993. Based on work completed to date, the Duluth researchers have concluded that 95th percentile maximum weekly average temperatures (i.e., the 95th percentile of the maximum weekly average water temperatures determined for all locations where a particular species has been reported) provide the best indicator of the thermal limits of a species' natural range. These values generally reflect the highest water temperatures at the southern extent of the species' range in the U.S. The F/T data sets are further separated into those north and south of the 40° latitude line to reveal geographic areas where a species may have adapted to higher thermal niche. Wherever 20 or more observations exist for a species on one side of the line, a northern- or southern-specific FTDMS value has been calculated.

When the naturalized range of a species is clearly contained within the southern border of the U.S., the FTDMS value generally is lower than laboratory-derived estimates of lethal temperatures such as the UTTL but higher than temperature criteria previously calculated from them, such as the Maximum Weekly Average Temperature for Growth or Short-term Maximum Temperature. For species with naturalized ranges that cross the southern border of the U.S., however, the FTDMS value does not approximate the highest temperature where that fish is to be found, because the 95th percentile temperature does not reflect the high end of the temperatures the fish tolerates, but the high end of temperatures found in the U.S.

Freshwater fish, by convention, are classified as belonging to a guild based on thermal habitat, either cold or warm. Studies based on thermal tolerances require greater resolution, however. The Duluth research team has used a classification system of three thermal guilds: cold, cool, and warm. However, as their database has become more extensive and as their statistical techniques improve, they have discovered that the only clear distinction is between cold-water fish and the others; the line between cool and warm is indistinct. In fact, using established conventions of recreational anglers as a basis for the defining thermal guilds leads to guild memberships with overlapping tolerances. For example, the estimated tolerances for rock bass (28.5) which is conventionally considered a "warm-water" fish is lower than the estimated tolerance for walleye (29.5), a cool-water fish. For consistency with economic literature, however, these conventions are retained for the present study.

Because of the geographical limitations to FTDMS data, Hokanson et al. (1989) recommend that for all warm-water fish, the Upper Zero Net Growth (UZNG) literature value be used instead of the FTDMS value. Further, they recommend that when this value is not available, an average of the available UZNG values for warm-water fish should be used. Because "warm-water fish" is a rather arbitrary grouping, however, the present study uses modified tolerances only for those fish whose naturalized range extends beyond the southern U.S. border. Exhibit 2-7 lists the species included in this study by guild. For most of these species, the most current FTDMS value is used as the thermal tolerance value.

Exhibit 2-7
Laboratory and Field-Derived
Thermal Tolerance Values for 32 Fish Species

Thermal Guild Species	Abbrev.	Thermal Tolerances[1] (°C)	Basis
Cold-water Species			
Pink salmon	PKS	18.8	FTDMS
Chum salmon	CMS	19.2	FTDMS
Brook trout	BKT	21.2	FTDMS
Mountain whitefish	MWH	22.3	FTDMS
Cutthroat trout	CUT	22.8	FTDMS
Coho salmon	COS	23.3	FTDMS
Rainbow trout	RBT	23.7	FTDMS
Brown trout	BNT	23.8	FTDMS
Chinook salmon	CHS	24.0	FTDMS
Cool-water Species			
Northern pike	NOP	28.8	FTDMS
Muskellunge	MUE	28.8	FTDMS
Walleye	WAE	28.9	FTDMS
Pumpkinseed	PMK	28.9	FTDMS
Yellow perch	YEP	29.4	FTDMS
Warm-water Species			
Smallmouth bass	SMB	28.4	FTDMS
Rock bass	RKB	28.9	FTDMS
Golden Shiner*	GOS	33.0	Average UZNG
Gizzard Shad*	GIS	33.0	Average UZNG
Sauger	SAR	30.3	FTDMS
Black crappie*	BLC	30.6	FTDMS
White crappie*	WHC	31.4	FTDMS
White bass*	WHB	35.0	UZNG
Largemouth bass*	LMB	35.5	UZNG
Bluegill*	BLG	36.0	UZNG
"Rough" Fish			
Brown Bullhead*	BRB	33.0	Average UZNG
Carp*	CAP	33.0	Average UZNG
Flathead catfish*	FCF	33.0	Average UZNG
Freshwater drum*	FWD	33.0	Average UZNG
Green sunfish*	GSF	33.0	Average UZNG
Small-mouth buffalo*	SAB	33.0	Average UZNG
White sucker	WTS	30.2	UZNG
Channel catfish*	CCF	35.0	UZNG

Notes:

[1]These values are primarily the FTDMS values from the Environmental Research Laboratory at Duluth, MN (personal communication John Eaton, July 7, 1994).

* These species' naturalized ranges extend south beyond the southern border of the U.S. Thermal tolerances for these species were calculated from the FTDMS data and the available UZNG values as follows: If both values were available, the higher of the two was chosen as the thermal tolerance. If no UZNG value was available, the species was assigned the average UZNG value for the species considered with ranges that did extend past the southern border.

Species with ranges that extend beyond the southern border of the U.S. are marked with an asterisk. For these species, we use the UZNG value where it is available (see Exhibit 2-6), or the average of values for "southern-border-crossing" fish (33°C). The resulting values in Exhibit 2-7 are also displayed on Exhibit 2-8.

The original version of the thermal model derived for this study used a set of fish species for which FTDMS data were available. This set has grown to include the fish species listed on Exhibit 2-9, and some species in the original set have dropped out because the data supporting their values could not meet the same level of statistical precision as the rest. The cutthroat trout and pumpkinseed (a sunfish), two recognized recreational fish species from the newer list, were substituted in the original set for fish that were dropped. The muskellunge was retained because of its recreational importance. It was assigned the thermal tolerance of the northern pike, a fish that has a similar naturalized range within the U.S. and similar laboratory values.

These values are the basis for the primary model runs presented here. Separately, a sensitivity analysis was performed to evaluate the effect of increasing and decreasing the tolerance for each fish. The Duluth research group has calculated standard errors for all the FTDMS values for all the species in their original set. These standard errors for FTDMS values used in the present study and the standard deviation of the UZNG for the species with extended ranges provided the basis for the sensitivity analysis, discussed in a later chapter.

2.3 FISH PRESENCE AT SAMPLE LOCATIONS

2.3.1 Checking Model Predictions for Baseline Presence

Perhaps the most meaningful test of this model's ability to predict natural ranges for fish species is how well it predicts ranges of fish habitat under baseline conditions. To a large extent, these "predictions" are circular: data for reported fish presence have been used to generate 95th percentile limits to maximum weekly average temperature for FTDMS, and these limits are the principal source of data used to determine the locations in which individual fish species are likely to occur. For some species of fish, however, the thermal tolerances used in this study are derived from laboratory data or generalized from similar fish species. Moreover (as discussed in Section 2.1.2) water temperatures used for this analysis have been derived from air temperatures reported for nearby weather stations, and do not necessarily equal true values. For these reasons, baseline ranges of fish habitat predicted by the model described in this report cannot necessarily be expected to correspond exactly to the ranges represented by the data used to derive FTDMS, and a comparison is useful.

As a test of the accuracy with which the model predicts natural ranges for fish species, its estimated ranges have been compared to those reported in the Audubon Society Field Guide to North American Fishes, Whales and Dolphins (Chanticleer Press, Inc., 1983). This guide provides maps and verbal description of natural habitat for most of the fish species included in this analysis. According to the Audubon Guide's introduction, its maps "show natural ranges; areas where the species is introduced are only included if the species is well established there." Because the maps are very small (about 2x2 cm), their interpretation as precise indicators of range is subjective. Nevertheless, the maps and verbal descriptions of the Audubon Guide have been used in this study to determine whether each species of fish should be expected to occur naturally within each of the 48 contiguous states of the U.S. Descriptions of the species and their ranges are contained in Appendix A. Fish presence within a particular state has been considered positive if the reported natural range appears to cover more than about 10 percent of the state's land area. Exhibits 2-10 through 2-13 show this interpretation of natural ranges as described in the Audubon Guide. Because the ranges mapped in these exhibits are discrete with respect to states, they are naturally "lumpier" and more expanded than those provided in the Audubon guide, for which the boundaries of shaded areas do not correspond to state boundaries.

Exhibits 2-14 through 2-15 (for Methods 1 through 3, respectively) compare model predictions of baseline habitat for cold-water fish to natural ranges provided by the Audubon Guide. Exhibit 2-14, compares predictions for Method (1), in which maximum weekly average water temperatures are assumed to equal unadjusted maximum weekly average air temperatures for the nearest climate station. Exhibit 2-15 compares predictions from Method (2), where Equation 2-1 (A=2.91, B=0.864) has been used to estimate maximum water temperatures from maximum air temperatures. Finally, Exhibit 2-16 provides the same comparison for Method (3), in which water temperatures are predicted with Equation 2-2 (B=0.864). For all three exhibits, states are unshaded (white) if the thermal model does not predict the presence of a fish in at least one station within the state, and the maps and discussions in the Audubon Guide do not suggest that the range for that fish covers at least 10 percent of the state's area. States are marked with cross-hatching if the Audubon Guide suggest the species is present in a state, and the thermal model predicts fish presence for at least one of the sample locations modelled in that state. States marked with horizontal lines indicate that the Audubon Guide reports the presence of a fish species but the thermal model estimates that water is too warm to support the fish (at all sampled locations within the state). Finally, states are marked with vertical lines if the model estimates that waters within the state should be cool enough to support the species, but its natural range (as described by the Audubon Guide) does not cover at least 10 percent of the state.

The abundance of vertical lines ("false positives") in these maps highlights a fundamental limitation to modelling based on upper thermal limits alone: a simple thermal model can indicate areas in which waters are too warm for a particular fish species (i.e., where the fish species *cannot* live), but will not necessarily indicate where the species *can*

EXHIBIT 2-8

Thermal Tolerance Values Used in Model

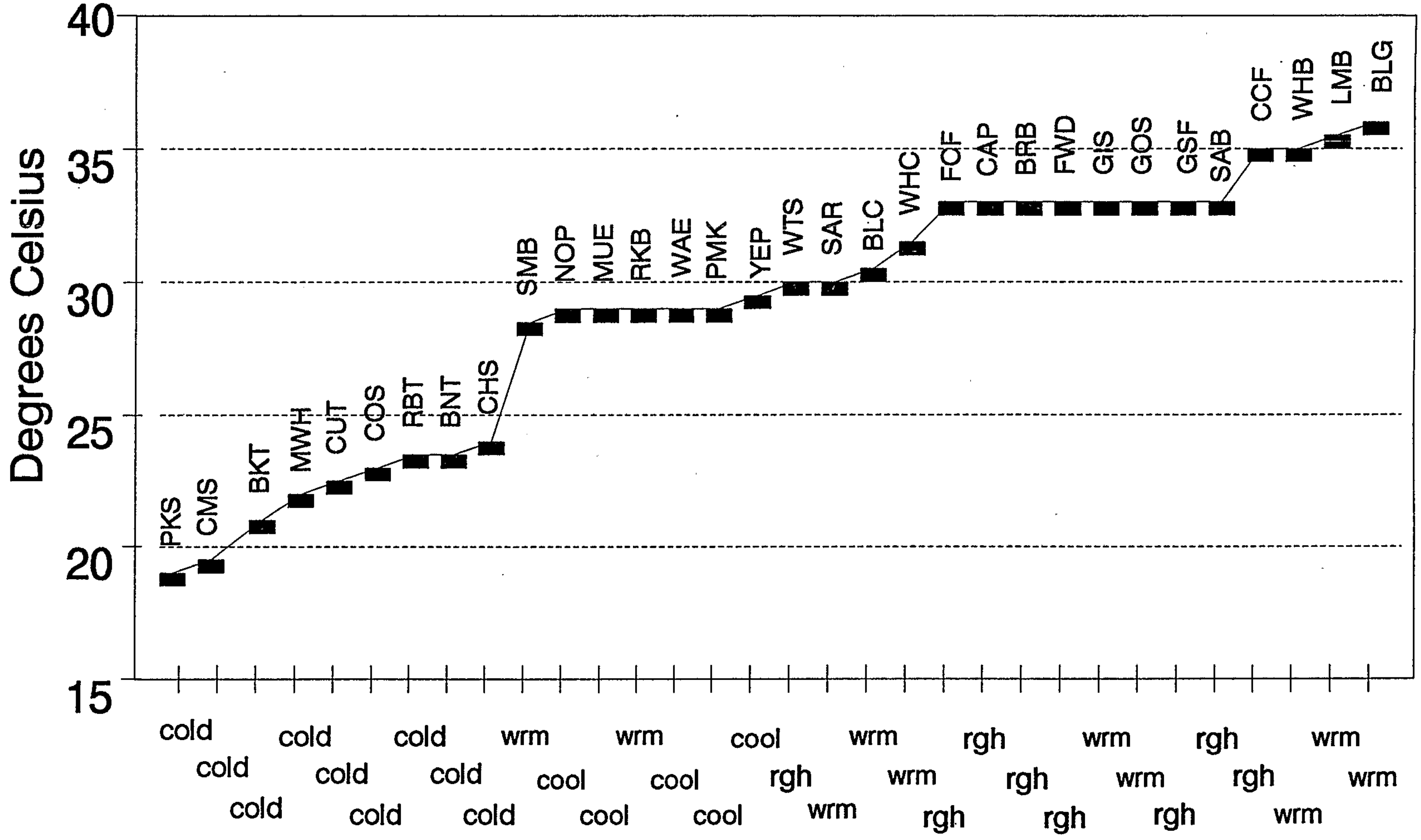


Exhibit 2-9
Additional Species in FTDMS Database

Species Name	FTDMS Value
Black Bullhead	31.0
Bluntnose Minnow	29.3
Black Nose Dace	26.0
Chain Pickerel	29.2
Creek Chub	27.1
Common Shiner	26.5
Cutthroat Trout	22.8
Emerald Shiner	31.0
Fathead Minnow	31.1
Golden Redhorse	29.6
Johnny Darter	26.2
Longear Sunfish	31.0
Longnose Gar	30.6
Mosquito Fish	31.3
Mottled Sculpin	26.2
Northern Hog Suck	29.6
Pumpkinseed Sunfish	28.9
Red Shiner	31.8
Silver Redhorse	29.6
Spotted Bass	30.9
Spottail Shiner	30.2
Spotfin Shiner	29.6
Warmouth	30.6
White catfish	30.9

These species have enough F/T data sets (>20) to calculate a meaningful 95th percentile Maximum Weekly Mean Temperature.

Exhibit 2-10

Natural Ranges for Cold Water Guild

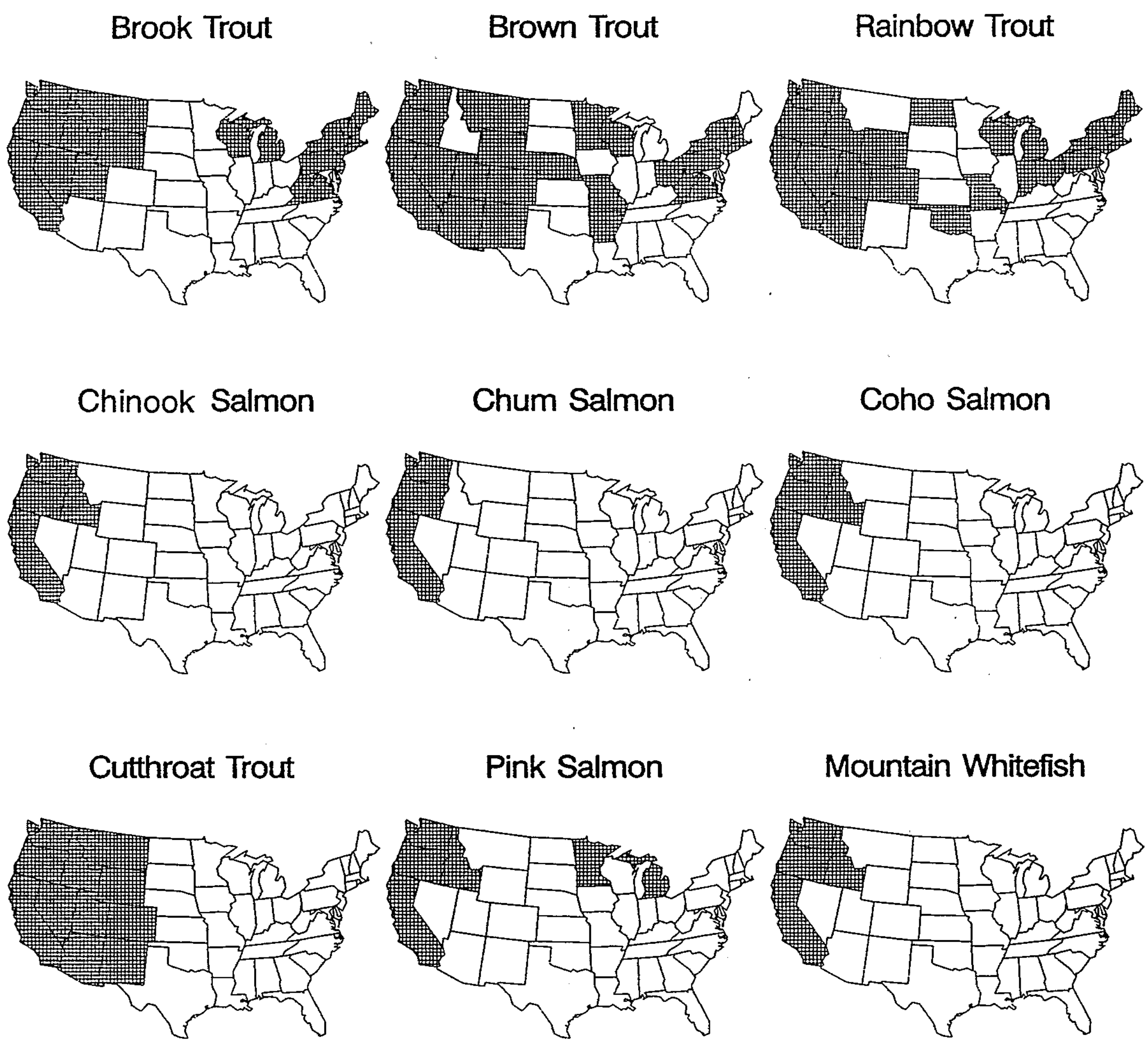
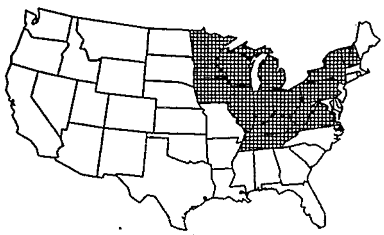


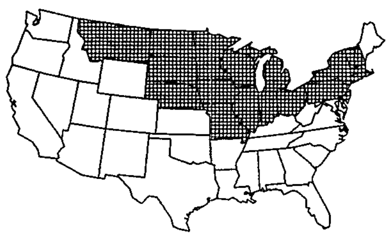
Exhibit 2-11

Natural Ranges for Cool Water Guild

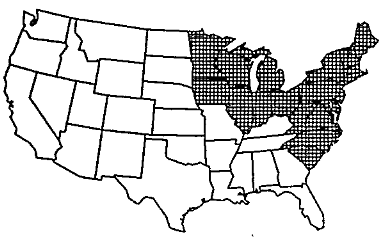
Muskellunge



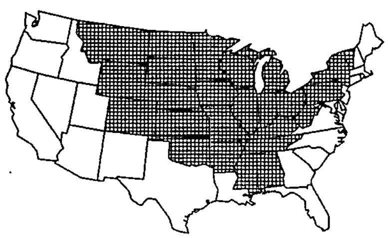
Northern Pike



Pumpkinseed



Walleye



Yellow Perch

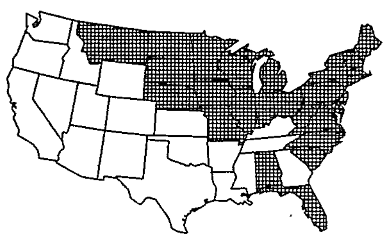
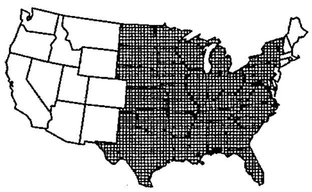


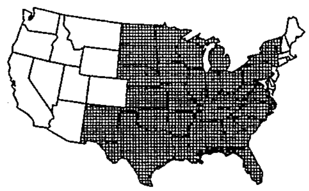
Exhibit 2-12

Natural Ranges for Warm Water Guild

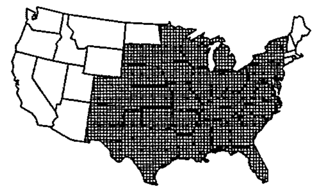
Black Crappie



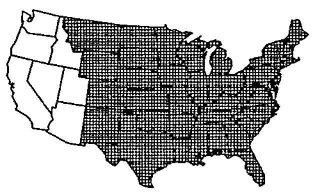
Bluegill



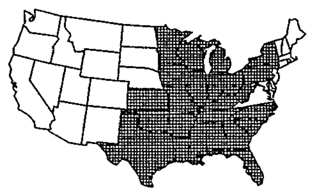
Gizzard Shad



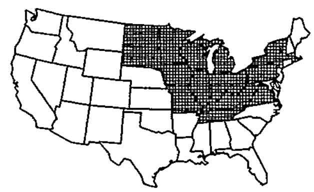
Golden Shiner



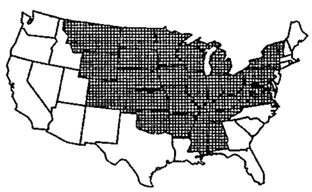
Largemouth Bass



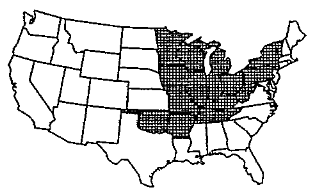
Rock Bass



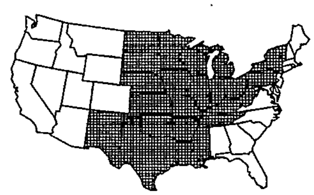
Sauger



Smallmouth Bass



White Bass



White Crappie

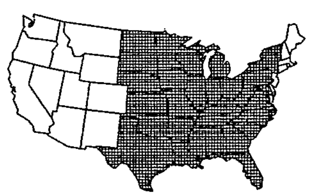


Exhibit 2-13

Natural Ranges for Rough Guild

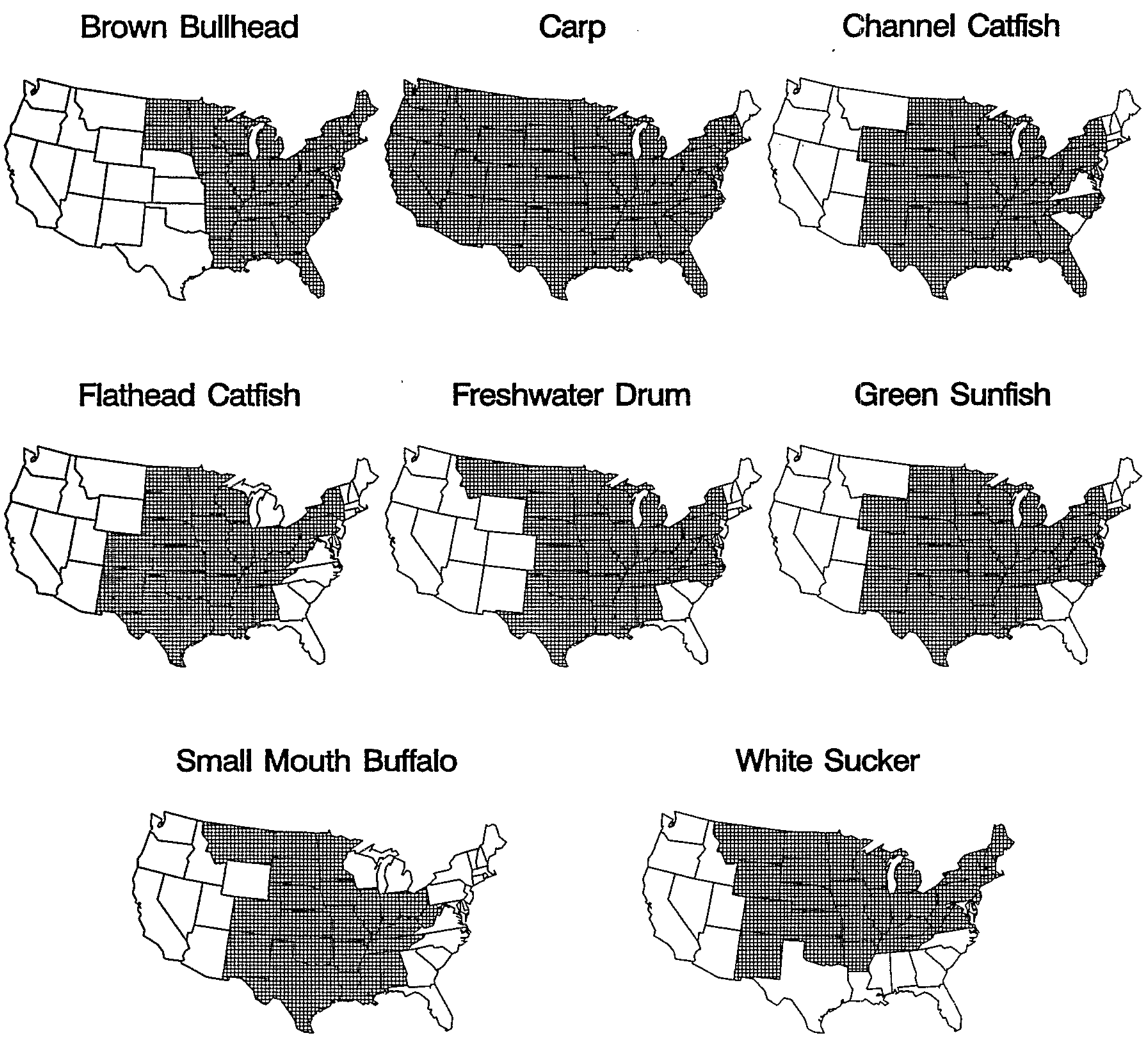


Exhibit 2-14
Comparison of Habitat Definitions
(Method 1)

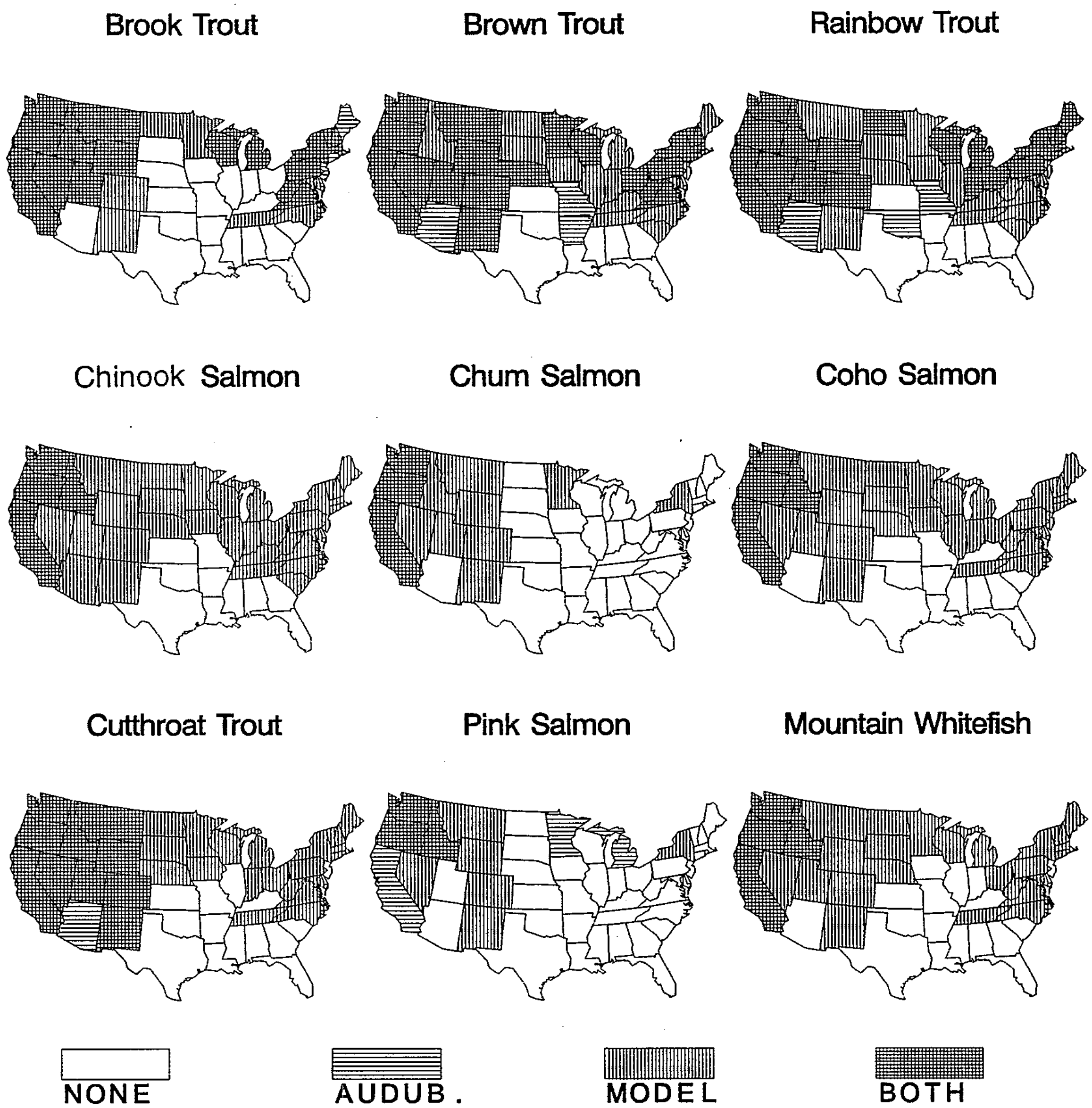


Exhibit 2-15
Comparison of Habitat Definitions
(Method 2)

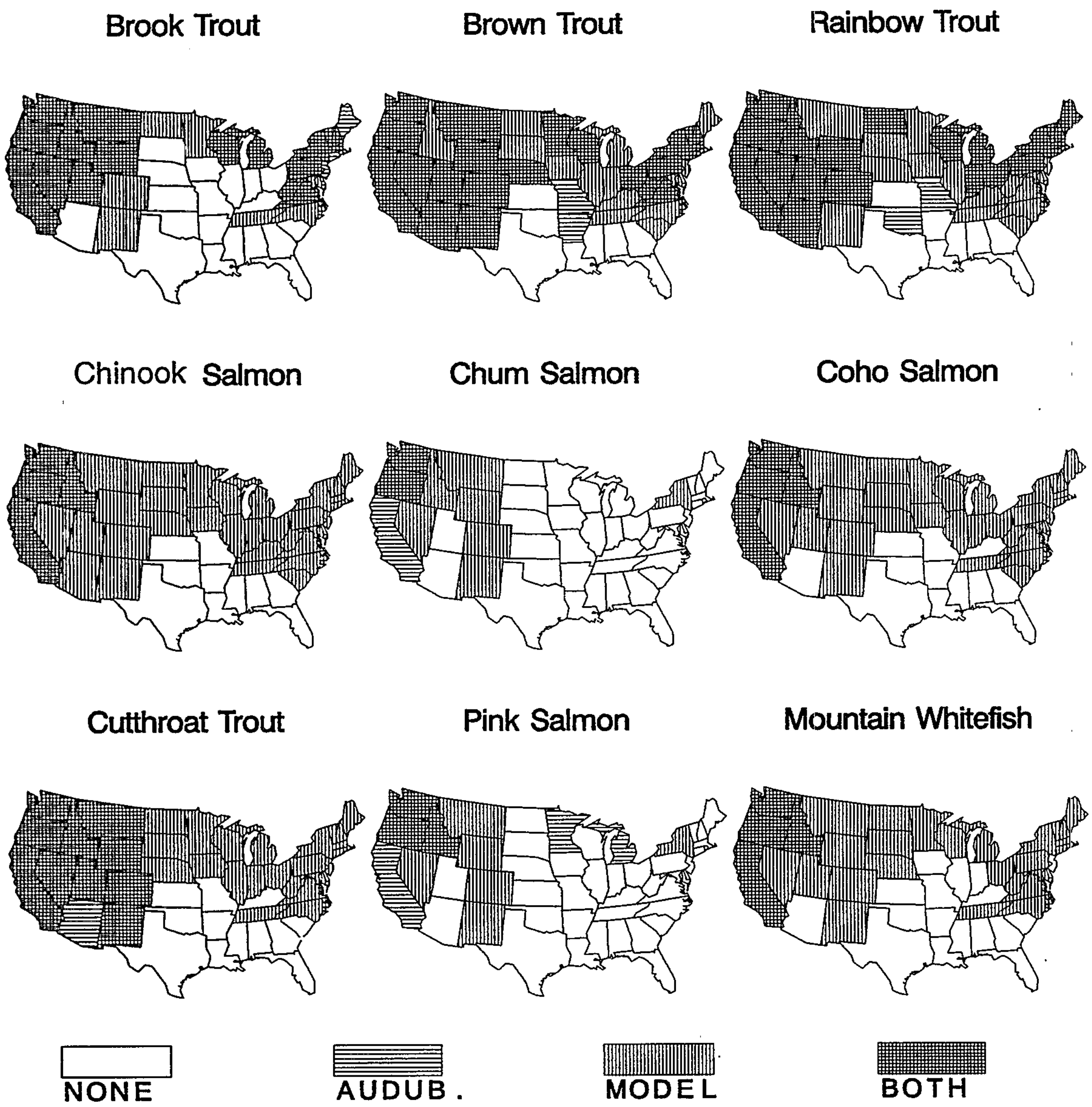
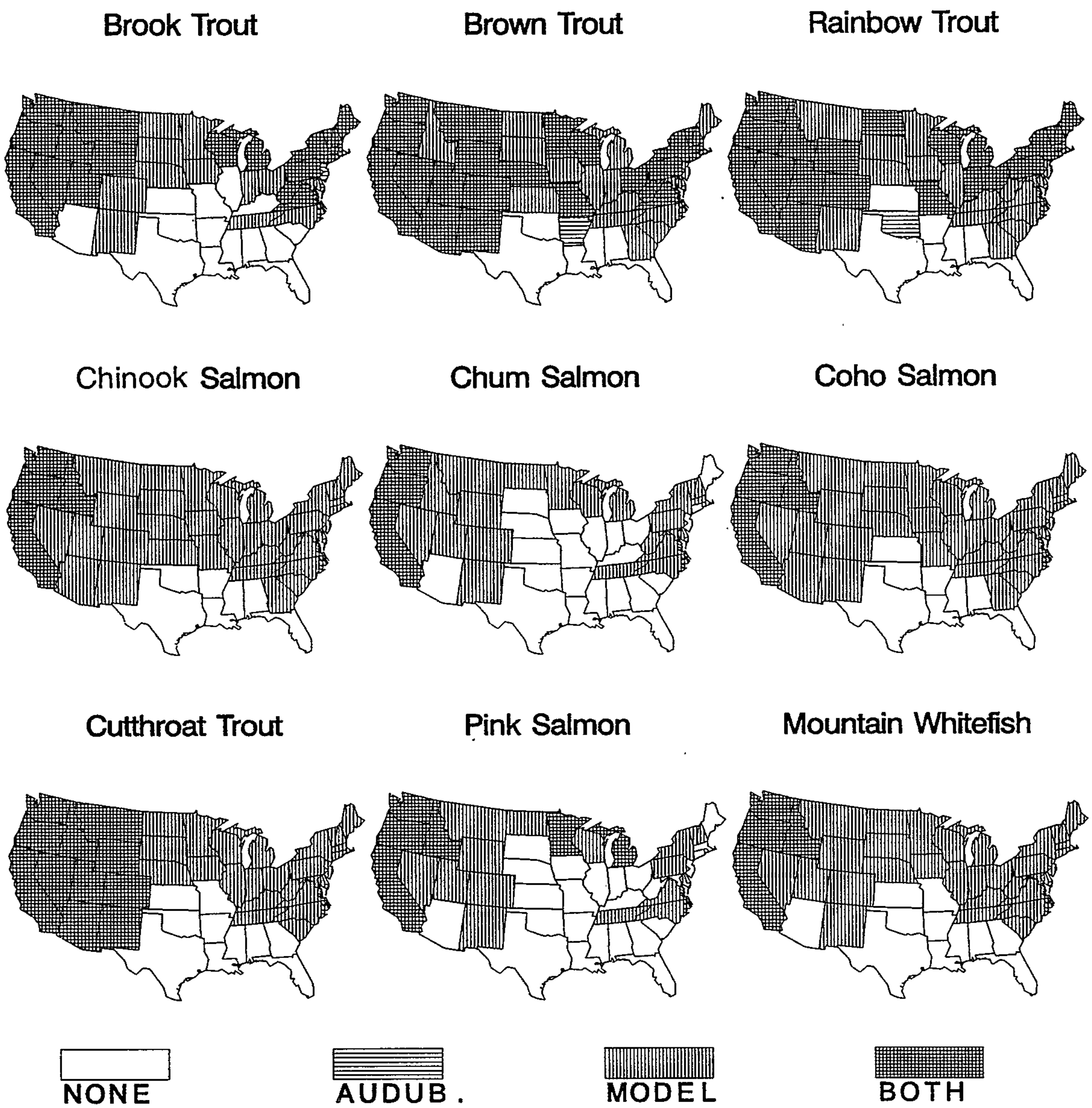


Exhibit 2-16
Comparison of Habitat Definitions
(Method 3)



live. Habitat ranges for individual species are not determined by water temperatures alone; they involve complex interactions of ecological, hydrological, and physical factors. To the extent thermal tolerances are separable from other limitations to habitat range, one can draw meaningful conclusions about the likely absence of individual fish species in waters above specified temperatures. Such conclusions cannot necessarily be drawn, however, about the expected presence of individual species in waters with lower temperatures. Based on thermal limitations alone, for example, coho salmon would be expected to thrive in South Dakota, but this anadromous species is in fact limited to the Pacific Coast. That the thermal model over-predicts natural ranges for all nine species of cold-water fish (especially the anadromous salmon of the West Coast) is therefore not surprising. Still, there seems to be a tendency for all three methods for estimating temperatures to over-predict natural ranges in the direction of warmer waters: there appears to be an approximate 1-2°C discrepancy between southern boundaries of range predicted by the model and those described by the Audubon Guide. In fact, for cool-water, warm-water, and rough guilds of fish species, these models predict that all 24 species should be present in all 48 states. This prediction is inconsistent with Exhibits 2-11 through 2-13, however, which suggest the existence of southern, thermal boundaries for muskellunge, northern pike, walleye, rock bass and small mouth bass.

Of special interest are the relatively few cases ("false negatives") where the simple thermal model predicts water too warm for a fish to be present, but the Audubon Guide reports presence of the fish. Exhibit 2-14 shows that Method (1) results in fourteen such false negative results: brook trout unexpected in Delaware, New Jersey, Connecticut and Maine, brown trout unexpected in Arizona, Missouri and Arkansas, rainbow trout unexpected in Arizona, Missouri and Oklahoma, Cutthroat Trout unexpected in Arizona, and Pink Salmon unexpected in California, Minnesota and Michigan. As can be seen from Exhibit 2-15 Method (2) reduces false negative results to thirteen cases, by allowing brown and rainbow trout in Arizona, but falsely predicting the absence of chum salmon from California. Those locations in California where chum salmon were formerly predicted (based on unadjusted air temperatures) were estimated to have maximum weekly average air temperatures lower than the tolerance for the salmon, 19.2°C. Because Equation 2-1 (A=2.91, B=0.864) predicts water temperatures higher than air temperatures for air colder than 21°C, its use results in the predicted absence of those salmon. Although Method (2) results in a net reduction of one false negative result in predicted habitat ranges, it slightly increases the count of false positive results. Exhibit 2-16 shows that Method (3) eliminates all but four of the false negative results observed with the other two methods (brook trout in Delaware and New Jersey, brown trout in Arkansas, and rainbow trout in Oklahoma), but at the cost of a marked increase in false positive results (209 compared to 158 for Method 1). With none of the three methods does a thermal model consistently under-predict the southern boundary of a fish species (i.e., generate false negatives along the southern boundary of a species' natural range).

Based on a comparison of results displayed in Exhibits 2-14 through 2-16, it appears that the simplest method for estimating temperatures (Method 1) predicts baseline ranges of habitat as well as the other two methods examined. Because of this finding, and because of concerns that regression results from Stefan and Preud'homme (1993) should not be generalized outside their appropriate context, this first analytic option has been selected as the preferred method for this analysis. Sensitivity of results to this selection will be discussed later.

2.3.2 Other Determinants of Habitat: Development of "Screens"

To overcome our model's tendency to predict fish presence in areas which, for reasons other than water temperature, are beyond the natural range of habitat for particular species, we use a "screen" to simulate limits imposed by other, non-thermal, constraints on natural ranges. For this purpose, we use the maps shown in Exhibits 2-10 through 2-13 to represent the natural ranges of habitat for each species of fish included in our analysis. A fish species is assumed present in waters near a particular station in our sample only if two conditions are met:

1) maximum weekly average water temperatures estimated for that station fall beneath the limit assigned to that species, *and*
2) the station falls within the ranges shown in 2-10 through 2-13.

By using such a screen we avoid projecting impacts from climate change for particular fish species in areas the species do not currently inhabit. Exhibit 2-17 maps screened estimates of baseline ranges for the nine species of cold-water fish examined in this analysis. For example, estimated baseline ranges for chinook, chum, coho and kokanee salmon are limited to the West Coast, even though estimated water temperatures are sufficiently low in several other states to support their presence. Conversely, rainbow trout are not assumed present in Missouri and Oklahoma (even though these states are included in the range mapped by the Audubon Guide) because estimated water temperatures for all sample stations are higher than the 24°C tolerance limit established for that species. In some states, estimated maximum water temperatures span a range that extends both above and below the tolerance of a particular species. In California, for example, maximum water temperatures at fewer than 50 percent of the stations in the sample are low enough to support chinook salmon (with a tolerance limit of 24°C), whereas more than 50 percent are cool enough to support coho salmon (with a tolerance of 23.3°C). In general, estimated water temperatures suggest that all nine cold-water species should be present at only selected stations along the southern and eastern boundaries of their ranges. Exhibits 2-18 through 2-19 display analogous screened ranges for cool-water, warm-water, and rough fish guilds. As mentioned earlier, the combinations of estimated water temperatures and tolerance limits used for this analysis appear to overestimate the southern and eastern extent of ranges from several of these species, such that expected fish presence along range boundaries (which are determined entirely by the Audubon Guide screen) is unconstrained.

From these species-specific estimates of habitability under baseline conditions, we aggregate our results to determine the presence of each thermal guild at each sample station. If, for example, at least one of the nine species of fish in the cold-water guild is expected present at a particular sample location, the cold-water guild is assumed represented at that location. As shown by Exhibit 2-21, members of the cold-water guild are expected in at least some sample locations in most states outside the Southeast. Members of the cool-water guild are expected in all states east of the Rocky Mountains excluding Georgia, which falls just outside the natural ranges of yellow perch and walleye. The aggregated range of the warm-water guild is similar to that for cool-water, except that Georgia is no longer excluded. Finally, members of at least one species from the rough guild (usually carp at a minimum) are expected in every station included in our sample, except where maximum weekly average temperatures exceed 33.0°C (the tolerance for carp) in California.

2.3.3 Effects of Climate Change on Maximum Temperatures

Using GCMs to Predict Changes to Fish Presence

Once a representation of "baseline" conditions has been constructed, the next analytic step is to simulate expected changes in fish presence as a function of increasing temperatures. For this step, location- and month-specific results from several general circulation models (GCMs) and global projections from several emission scenarios (IPCC -- IS92a, IS92c, and IS92e) developed by the Intergovernmental Panel on Climate Change (IPCC, 1992) provide the basis for predicting incremental changes in the maximum weekly average air temperature expected for each of our 996 sample locations. In the current model, the GCM output provides a range of possible geographic and temporal patterns of temperature increase, while the IPCC scenarios set the global mean average temperature increment to which the GCM output is normalized.

The GCMs have been developed to simulate the physical processes of the atmosphere and oceans and to calculate climatic parameters under baseline and increased CO_2 conditions. Models originating from four different research groups were used in this report, and both equilibrium models and transient models are included. Equilibrium models predict the temperature of a system that was allowed to reach equilibrium with a doubled CO_2 concentration, and they show no time-dependence. References for the equilibrium models include:

- GFDL (Geophysical Fluid Dynamics Laboratory: Manabe and Wetherald, 1987);
- GISS (Goddard Institute for Space Studies: Hansen et al., 1983);
- OSU (Oregon State University: Schlesinger and Zhao, 1988); and
- UKMO (United Kingdom British Meteorological Office: Wilson and Mitchell, 1987).

The National Center for Atmospheric Research (NCAR) made this data available in electronic form. Transient modelling is intended to give a more realistic representation of how quickly the climate will change over time with dynamically increasing greenhouse gas concentrations. Currently, NCAR has available data from transient runs from four different models, including the GFDL. The GFDL transient model (Stouffer et al., 1989) uses a coupled ocean-atmosphere module, which introduces some lag time due to the damping effect of the oceans. Transient data from the GFDL were also included in this study.

While the GCMs are the best available estimates of geographic variation in climate change, their spatial resolution is still rather coarse: they treat the globe as a set of grids, varying in size from 4 by 5 degrees of latitude and longitude for OSU to 8 by 10 degrees for GISS. Obviously there is significant climatological variation within grid cells of this size, and the boundaries of the grid cells are artificial. However, the performance of the four equilibrium models in selected control runs under a 1 x CO_2 equilibrium scenario was evaluated and compared to a real-time climatic data set by climatologists in 1991 (U.S. EPA, 1991). They found that the GCM results and the empirical data were especially compatible over North America, where the temperatures projected by the models matched observed climate data relatively well, especially in summer, within 2°C in most cases. The patterns produced by the transient and equilibrium versions of the models are generally similar over North America.

Greenhouse warming is caused by anthropogenically increased levels of greenhouse gases. The GCMs are designed to calculate the level of warming that would be caused by a certain concentration of these gases in the atmosphere, but they cannot predict what those concentrations will be. The actual concentrations of greenhouse gases depend on emissions of CO_2 and other greenhouse gases. IPCC (1992) focused intentionally on emissions scenarios, predicting changes in the global emissions based on current population forecasts, energy and industry forecasts, political events and changing economic circumstances worldwide, current studies on tropical deforestation and forest biomass, and the best estimates of uncertainty. The authors developed a range of scenarios, with IS92a representing the median estimate, assuming internationally agreed controls on SOx, NOx, and non-methane VOCs. Scenario IS92c reflects the results of a low-estimate level of emissions due to low estimates of population growth, and scenario IS92e represents a high-end level of emissions, resulting from a higher level of economic growth. In addition to this range of emissions, the IPCC also presented a range of sensitivity to the level of emissions in scenario IS92a, representing best-, high-, and low-estimate predictions of global mean temperature increments resulting from the mid-range estimate of emissions. While there are a number of outstanding issues in the modelling of climate change, such as possible differentials in day- and night-time temperature increases, the IPCC's view was judged to be the most reliable interpretation of the current state of science.

This study uses temperature increments from the GCMs, normalized to correspond to these three emission scenarios. This approach allows the use of temperature increments specific to the individual months and locations, adjusted to be consistent with IPCC projections. A total of 22 combined scenarios were compiled for this study. For each

Exhibit 2-17
Baseline Habitability for Cold-Water Fish

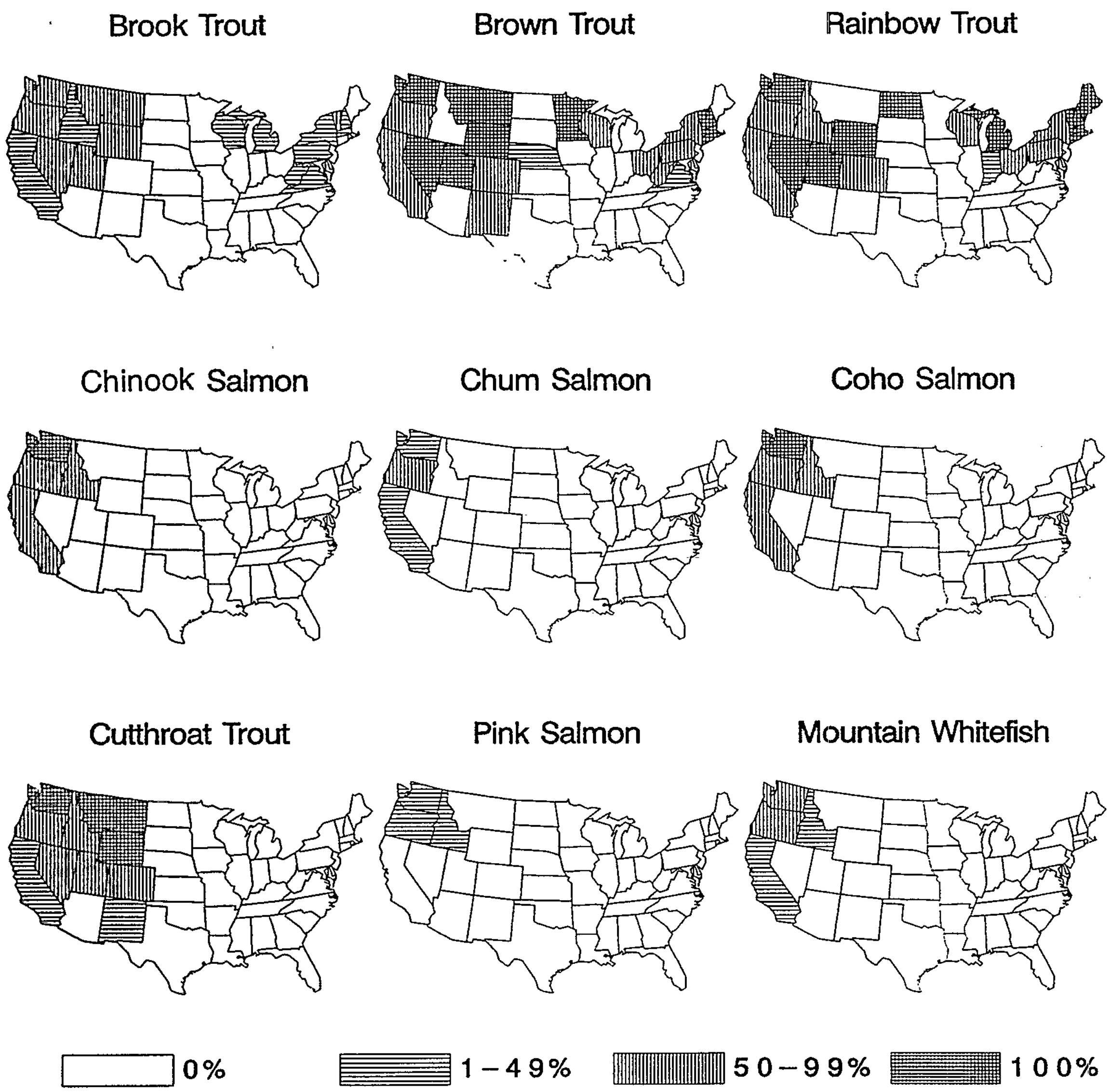


Exhibit 2-18
Baseline Habitability for Cool-Water Fish

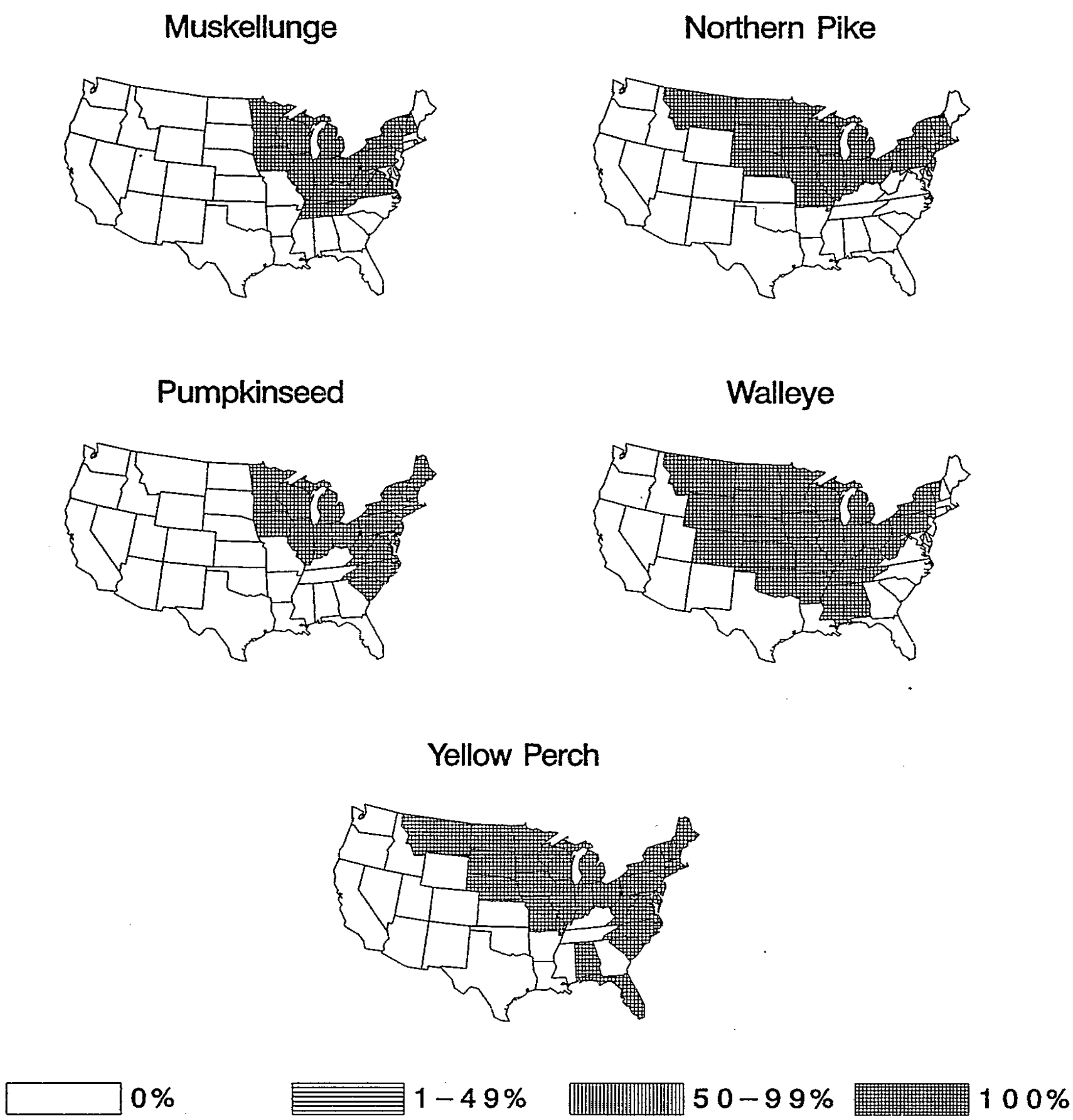


Exhibit 2-19
Baseline Habitability for Warm-Water Fish

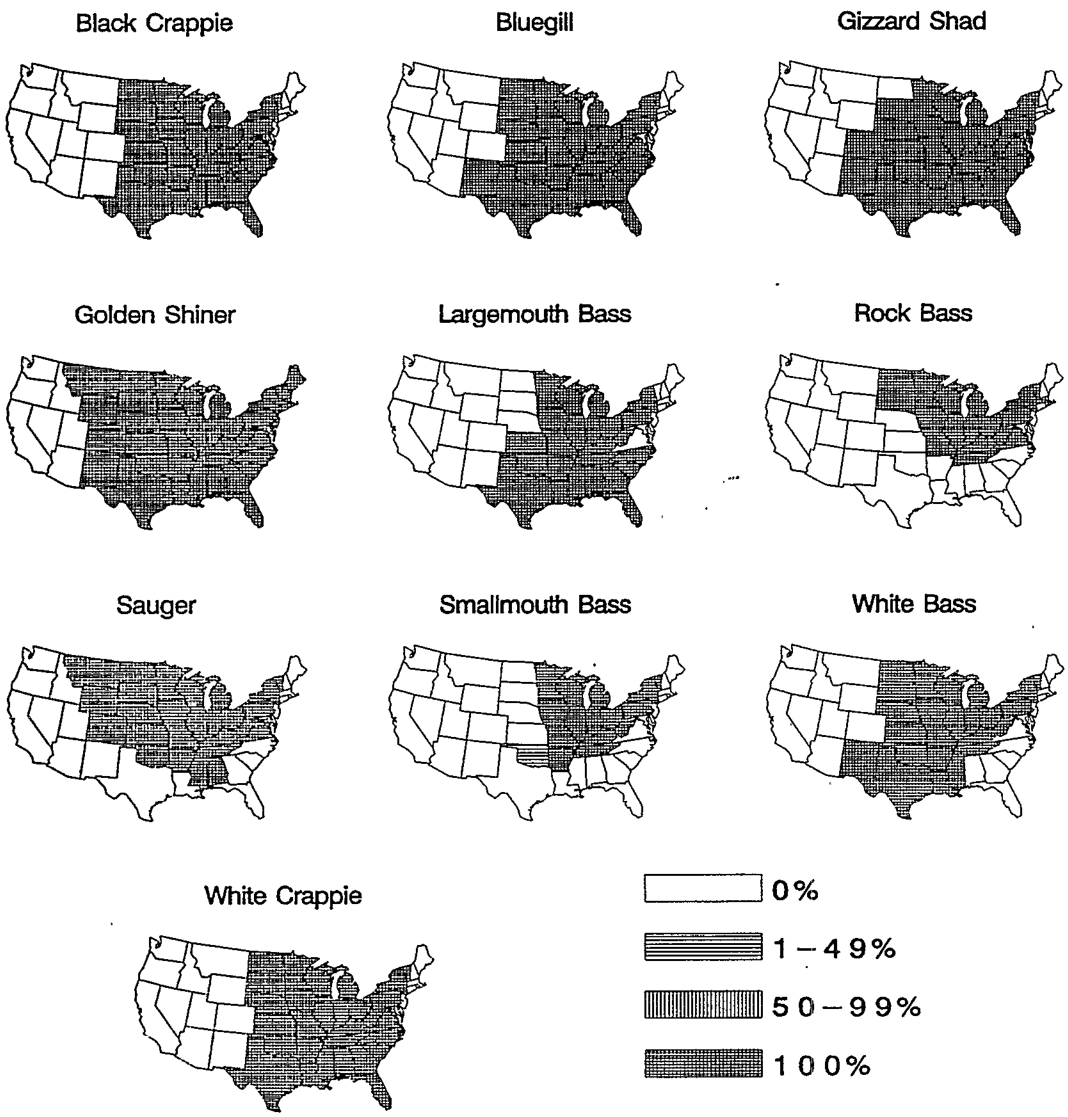


Exhibit 2-20
Baseline Habitability for Rough Fish

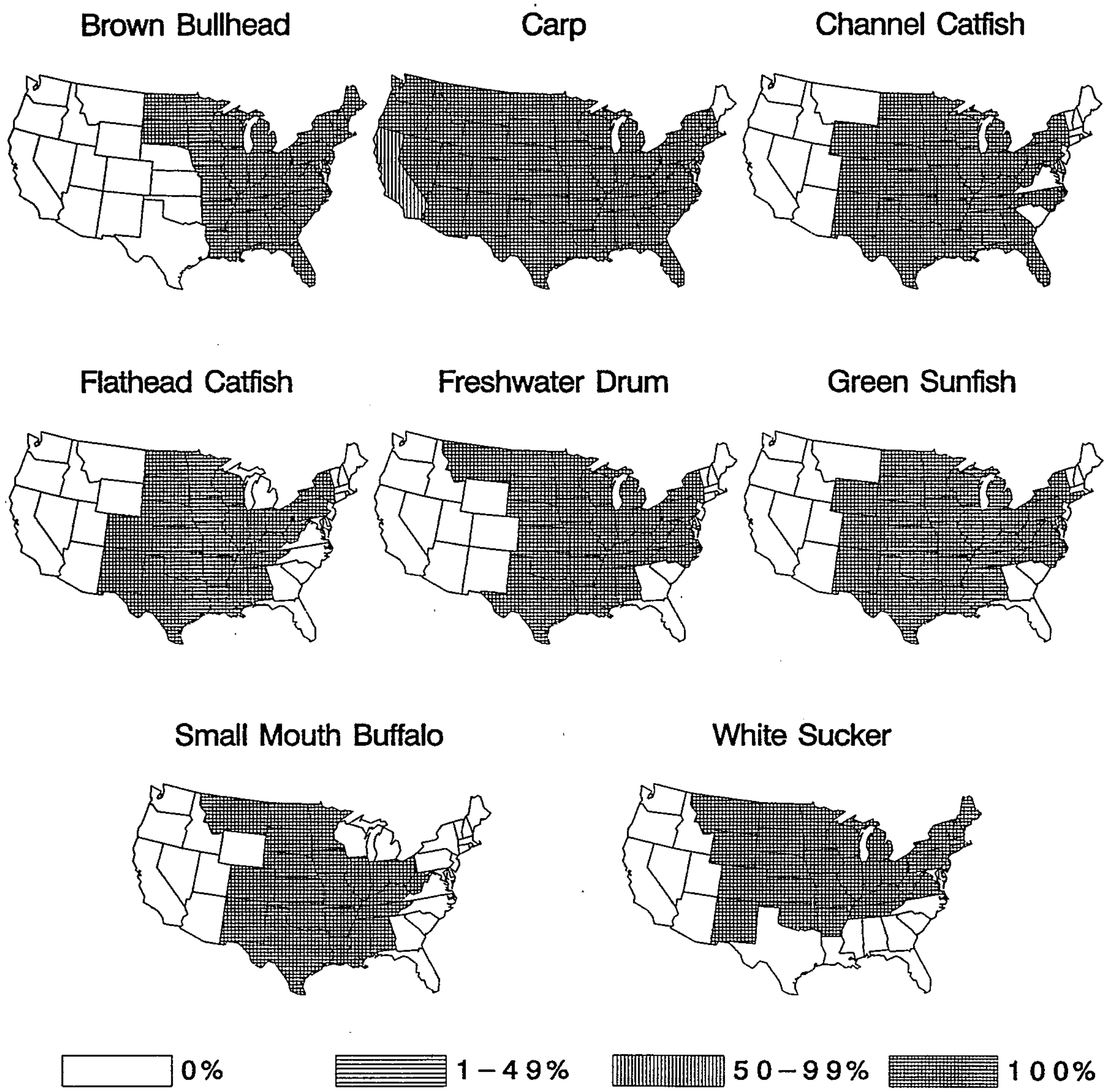
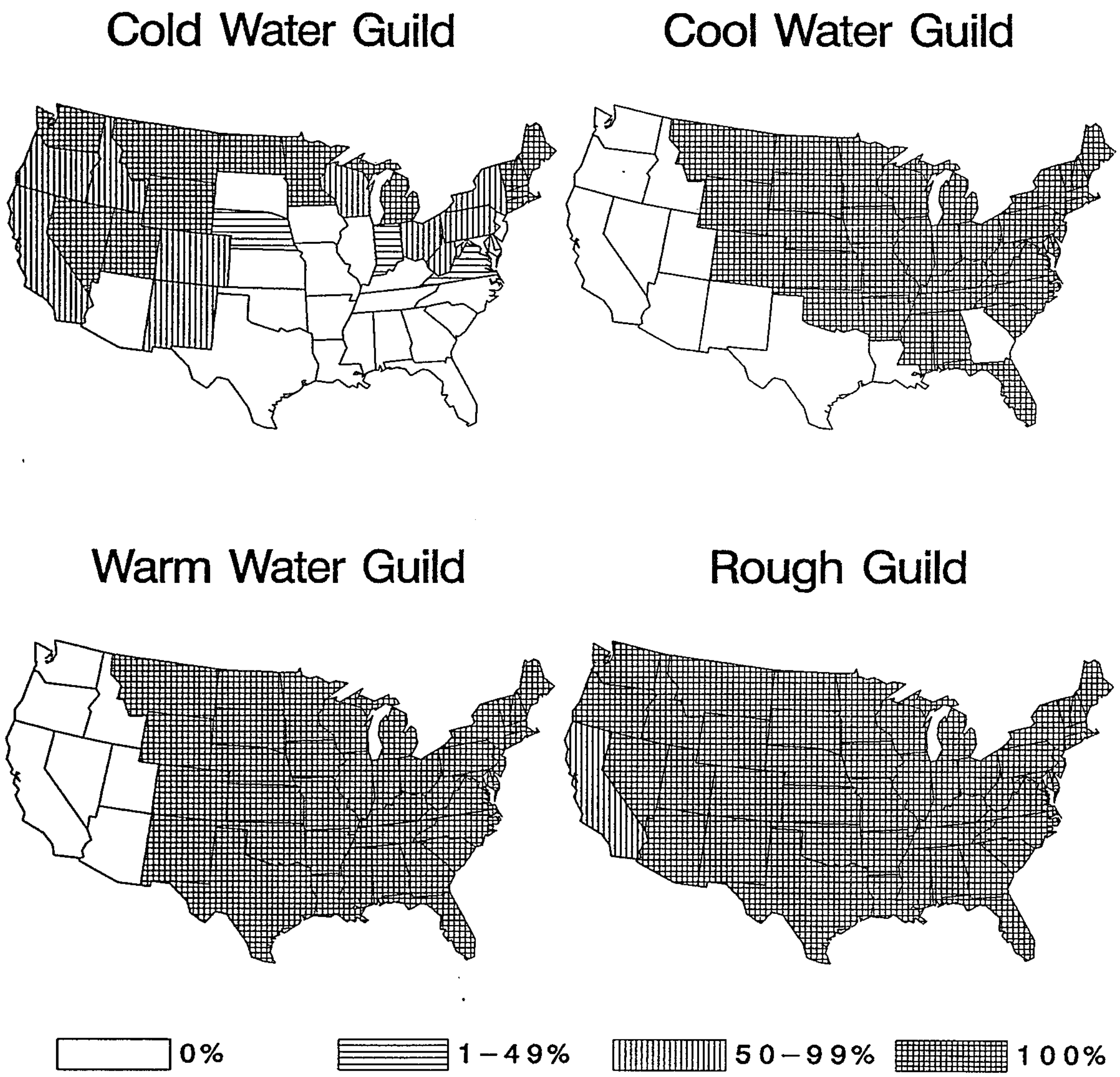


Exhibit 2-21
Baseline Habitability by Guild



scenario, the cell-month temperature increments from a GCM (ΔT_L, L for local) are multiplied by a normalization factor that is the ratio of the global annual mean temperature increment indicated by the IPCC emissions scenario ($GAMT_{IPCC}$), for a given climate sensitivity assumption, divided by the global annual mean temperature increment obtained by averaging all the GCM cells over the entire grid over the 12 months ($GAMT_{GCM}$). The result is a normalized cell-month temperature increment, $\Delta T_L'$.

$$\Delta T_L' = (GAMT_{IPCC}/GAMT_{GCM})\ \Delta T_L$$

The scenarios in this study include both equilibrium and transient runs of the models. The equilibrium scenarios are constructed from doubled-CO_2 equilibrium runs from the four listed models scaled to each of the three climate sensitivity estimates used by IPCC. The transient runs of the GFDL model were scaled to time-dependent projections from scenarios IS92a, IS92c, and IS92e.

This approach produced twelve equilibrium scenarios, for the four GCMs normalized to each of the three proposed sensitivity estimates as they were applied to emission scenario IS92a. The resulting scenarios are summarized in Exhibit 2-22. The equilibrium data are not tied to a specific calendar year, but to a time of doubled CO_2. According to 1992 IPCC Supplement Figure Ax.4, the year when the global annual mean temperature increment reaches the level of predicted warming under emission scenario IS92a varies significantly for different sensitivity estimates. The resulting increase from low estimates of doubled-CO_2 sensitivity, 1.5°C, may occur by 2080, while the "best estimate" 2.5° warming may occur at 2090, and the year when the high-sensitivity estimate of 4.5°C would be reached is 2105.

Temperature increments from the transient GFDL runs were obtained for two decades, referenced to a baseline representing the climate in 1961-90. The "1.16°C decade" run of the transient GFDL was presented to the IPCC 1992 working groups because its global average temperature increase most closely matches the 1.16°C global mean temperature increase projected to occur by 2050 according to the IS92a "best estimate" projections. The "eighth decade" was also provided for studies designed to consider a stronger degree of forcing. For the current study, the local temperatures from these decades were normalized to a range of IS92 scenarios: IS92a with "best," low, and high sensitivity assumptions; IS92c with "best estimate" sensitivity; and IS92e with "best estimate" sensitivity. The "1.16°C" decade was normalized to the IS92 projections for 2050, and the "eighth decade" was normalized to the 2100 projections to coincide with the years generally considered in climate change analysis. The global annual mean temperatures used in these normalizations are presented in Exhibit 2-23.

For the calculations reported here, "forcing" values for air temperature (i.e., expected increments in temperature due to increased CO_2) are obtained automatically from electronic files of scaled GCM model output corresponding to one of the constructed scenarios listed on

Exhibit 2-22
Global Annual Mean Temperature Increases Used to Scale Equilibrium GCM Results

GCM Run	GCM Climate Sensitivity	IPCC Climate Sensitivity		
		Low	Best estimate	High
GFDL/ Equilibrium	4.0°C	1.5°C[1] at doubled CO_2 GF2	2.5°C[1] at doubled CO_2 GF1	4.5°C[1] at doubled CO_2 GF3
GISS/ Equilibrium	4.2°C	1.5°C at doubled CO_2 GI2	2.5°C at doubled CO_2 GI1	4.5°C at doubled CO_2 GI1
OSU/ Equilibrium	2.8°C	1.5°C at doubled CO_2 OS2	2.5°C at doubled CO_2 OS1	4.5°C at doubled CO_2 OS3
UKMO/ Equilibrium	5.2°C	1.5°C at doubled CO_2 UK2	2.5°C at doubled CO_2 UK1	4.5°C at doubled CO_2 UK3

Notes:
[1] IPCC 1992 (p. 10)

Exhibits 2-22 or 2-23, based on the latitude, longitude, and calendar dates appropriate for the weekly average temperatures of each sample location. These values are added to baseline temperatures, and the maximum weekly average is re-computed. Exhibit 2-24 summarizes forcing values taken from each of the four equilibrium "best estimate" scenarios for each of the 48 contiguous states. This exhibit reports averaged values of forcing for each state; actual values can vary within a state according to each station's location and the month in which the new maximum temperature occurs. Exhibit 2-25 shows ranges of temperatures expected in each state after climate change. Similar maps are provided for the GI1, OS1, UK1, TR1, and TR2 scenarios in Appendices B-F.

To determine how climate change might affect the natural ranges of individual fish species, these altered estimates of maximum weekly average water temperature are compared to the thermal tolerances previously established for each fish species. As with the same step for baseline conditions, the "screen" constrains the areas considered to those within the naturalized range of each species. Next, the new estimates for fish presence after climate change (expressed in fishable acres per state) are subtracted from the corresponding estimates for baseline conditions to derive estimates for the loss of fish presence expected as a result of increases in temperature.

Exhibit 2-23
Global Annual Temperature Increases Used to Scale Transient GCM Results

GCM Run	Climate Sensitivity	Emission Scenario				
		IS92C (low)	IS92A (mid)			IS92e (high)
		IPCC Climate Sensitivity				
		Best estimate	Low	Best estimate	High	Best estimate
GFDL/ Transient "1.16°C decade"	1.32°C	1.1°C[2] in 2050 TR7	0.15°/decade = 0.9°C[3] in 2050 TR3	0.25°/decade = 1.5°C[3] in 2050 TR1	0.4°/decade = 2.4°C[3] in 2050 TR5	1.8°C[2] in 2050 TR9
GFDL/ Transient "Eighth decade"	2.6°C	1.5°C[2] in 2100 TR8	0.15°/decade = 1.65°C[3] in 2100 TR4	0.25°/decade = 2.75°C[3] in 2100 TR2	0.4°/decade = 4.4°C[3] in 2100 TR6	3.5°C[2] in 2100 TR10

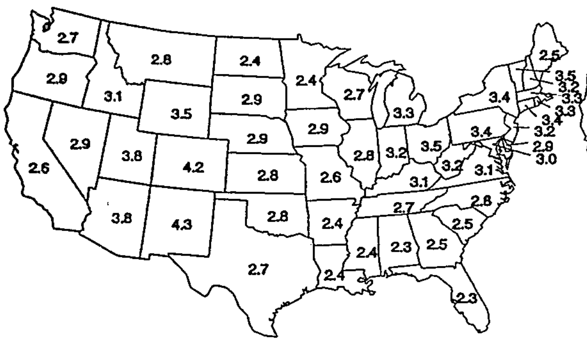
Notes:
[1] IPCC 1992. (p. 10)
[2] IPCC 1992 Annex Figure Ax.3 (p. 174)
[3] IPCC 1992 as interpreted by Neil Leary, EPA, in memo to ECF dated April 13, 1994.

2.4 RESULTS

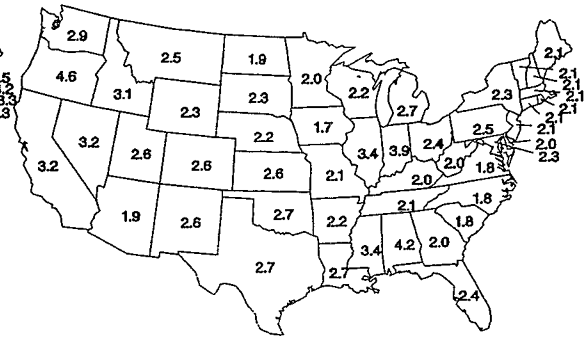
Exhibits 2-26 provides summary maps of results for all four guilds for the GFDL equilibrium and Exhibits 2-27 through 2-30 provide summary maps of results for each species, based on forcing values taken from the GFDL model. In each of the maps included in this exhibit, a state is shaded with cross-hatching if 100 percent of its original fishable acres of a particular species or guild are lost as a result of CO_2 doubling (i.e., the waters at all sample locations are expected to exceed thermal tolerances for that species or guild). Of course, if the species or guild was not present under baseline conditions, it cannot disappear because of climate change: states where no loss occurs (either because the fish was originally absent or because warming is insufficient to eliminate it) are not shaded. Those states experiencing partial losses of habitat for a species or guild are marked with horizontal or vertical lines, where the percent loss is calculated as the number of fishable acres lost divided by the original number of fishable acres (before climate change). Appendices B through F provide analogous summary maps based on the other three GCMs.

Exhibit 2-24
Average Increment to Maximum Weekly Temperature from CO_2 Doubling

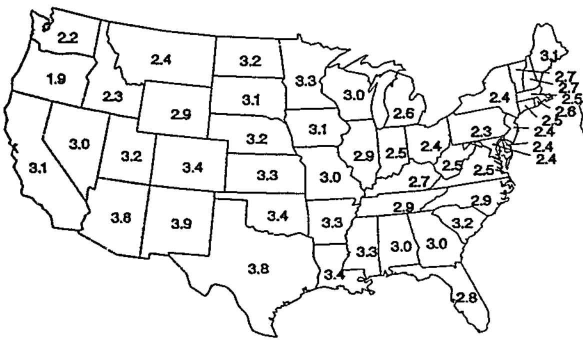
GF1



GI1



OS1



UK1

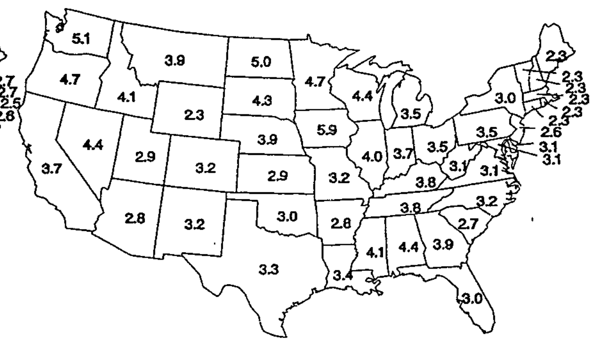
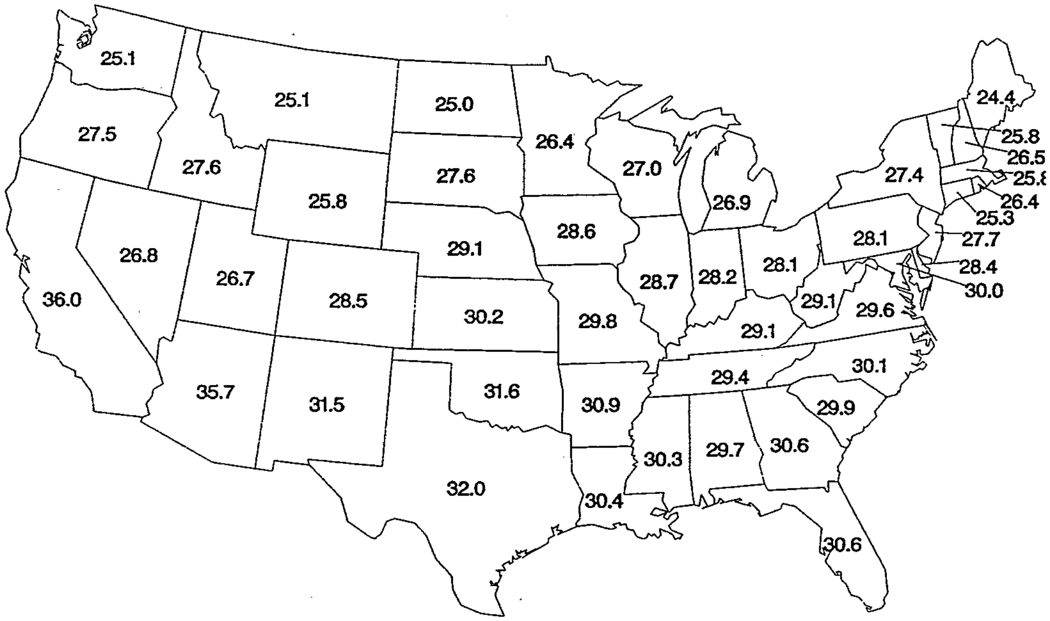


Exhibit 2-25
Maximum Weekly Average Temperature After CO_2 Doubling (GF1)

Highest Maximum per State



Lowest Maximum per State

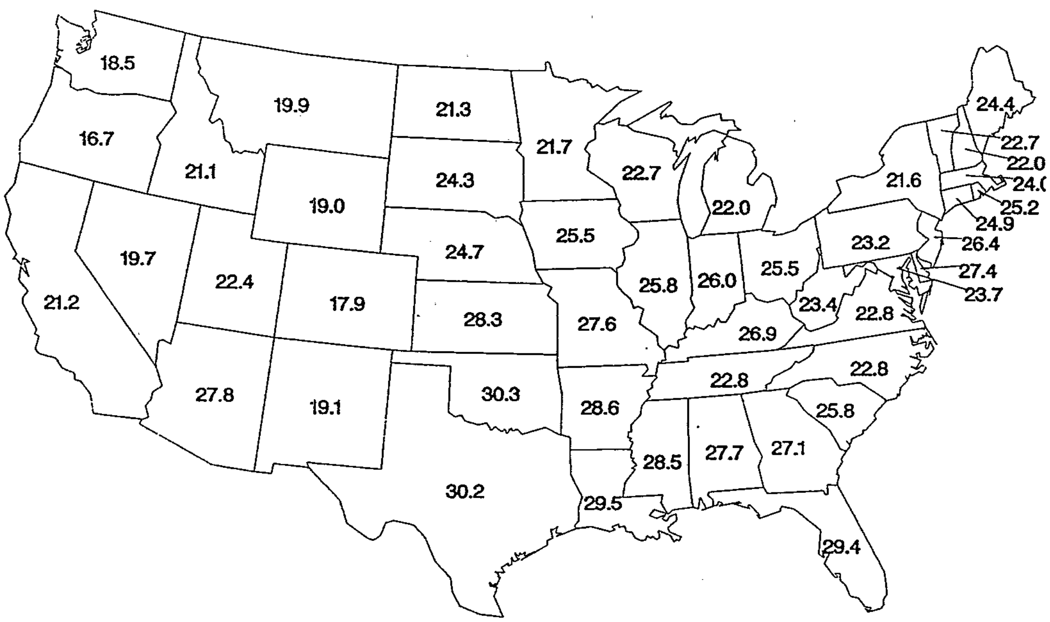


Exhibit 2-26
Loss of Habitat by Guild (GF1)

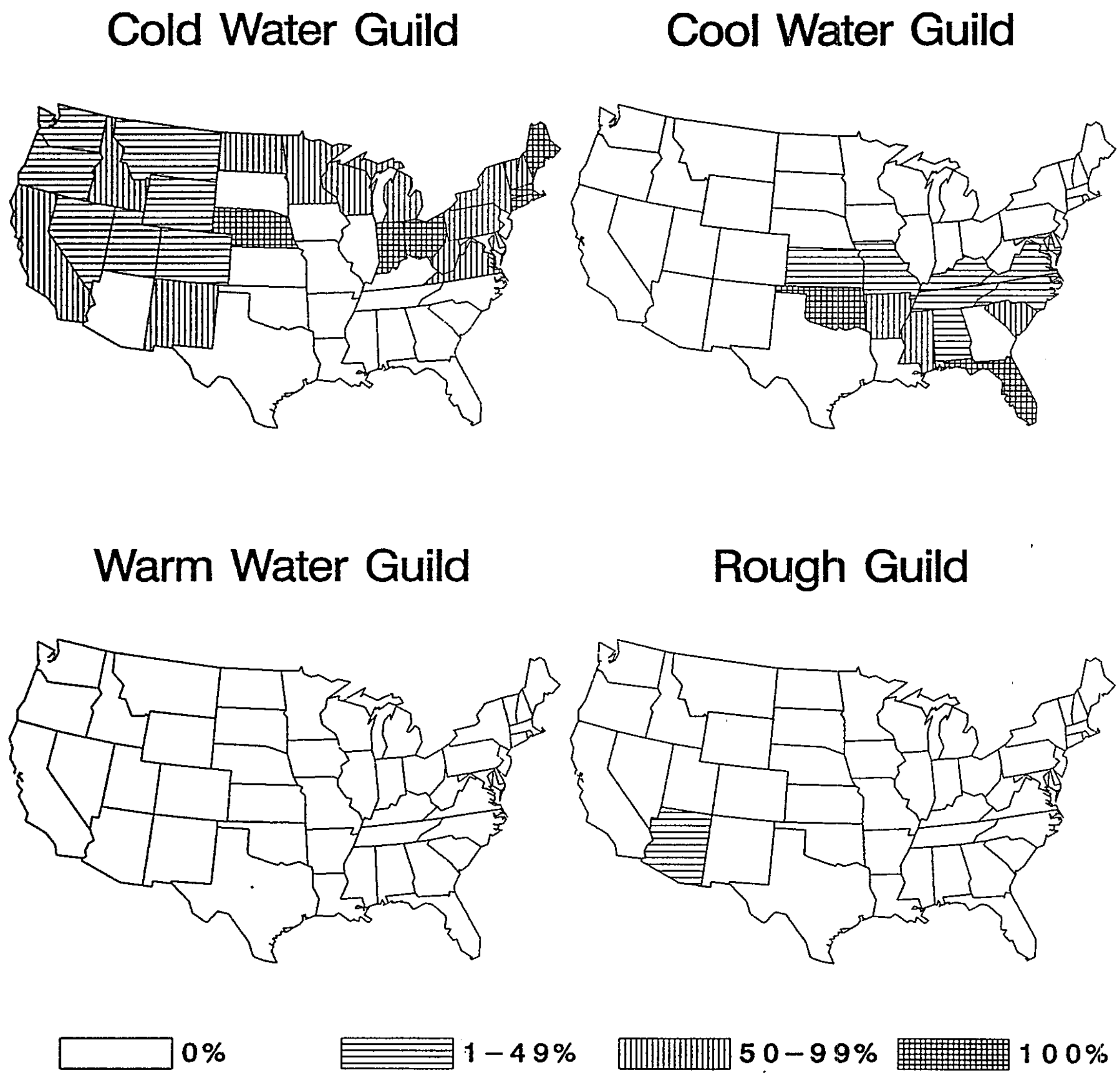


Exhibit 2-27
Loss of Habitat for Cold-Water Fish (GF1)

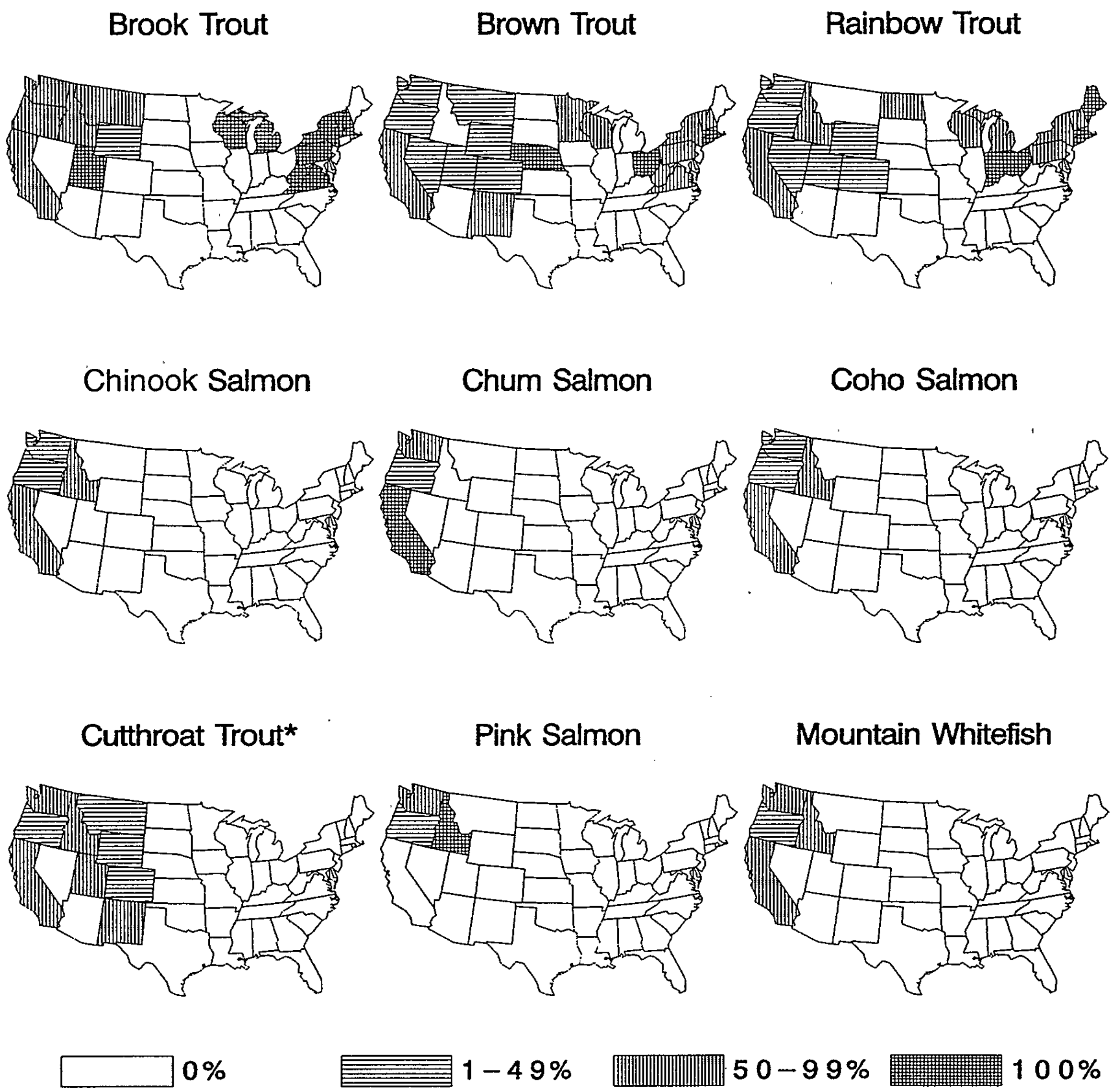
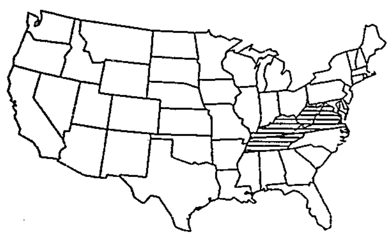
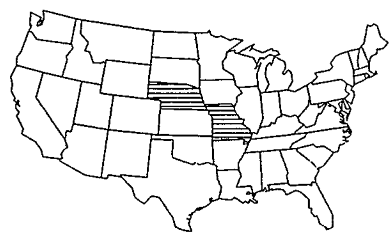


Exhibit 2-28
Loss of Habitat for Cool-Water Fish (GF1)

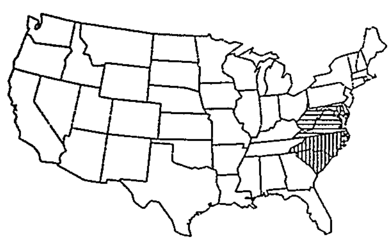
Muskellunge



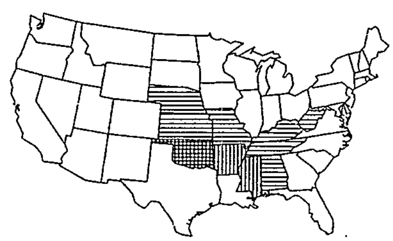
Northern Pike



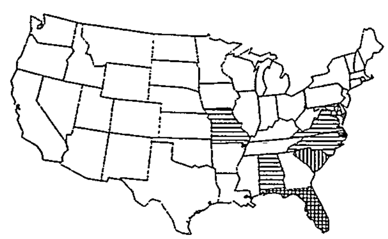
Pumpkinseed



Walleye



Yellow Perch



0%   1-49%   50-99%   100%

Exhibit 2-29
Loss of Habitat for Warm-Water Fish (GF1)

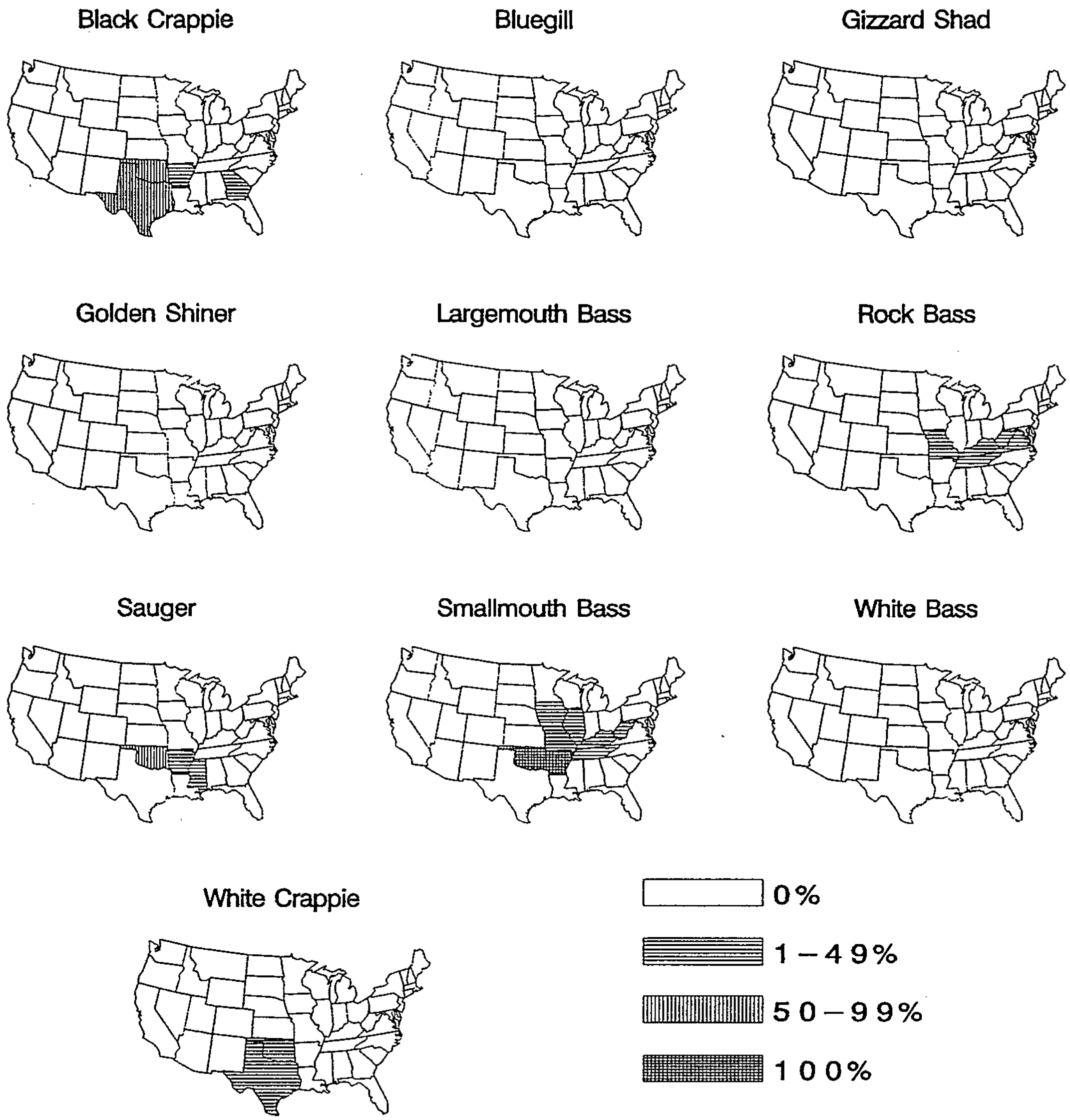
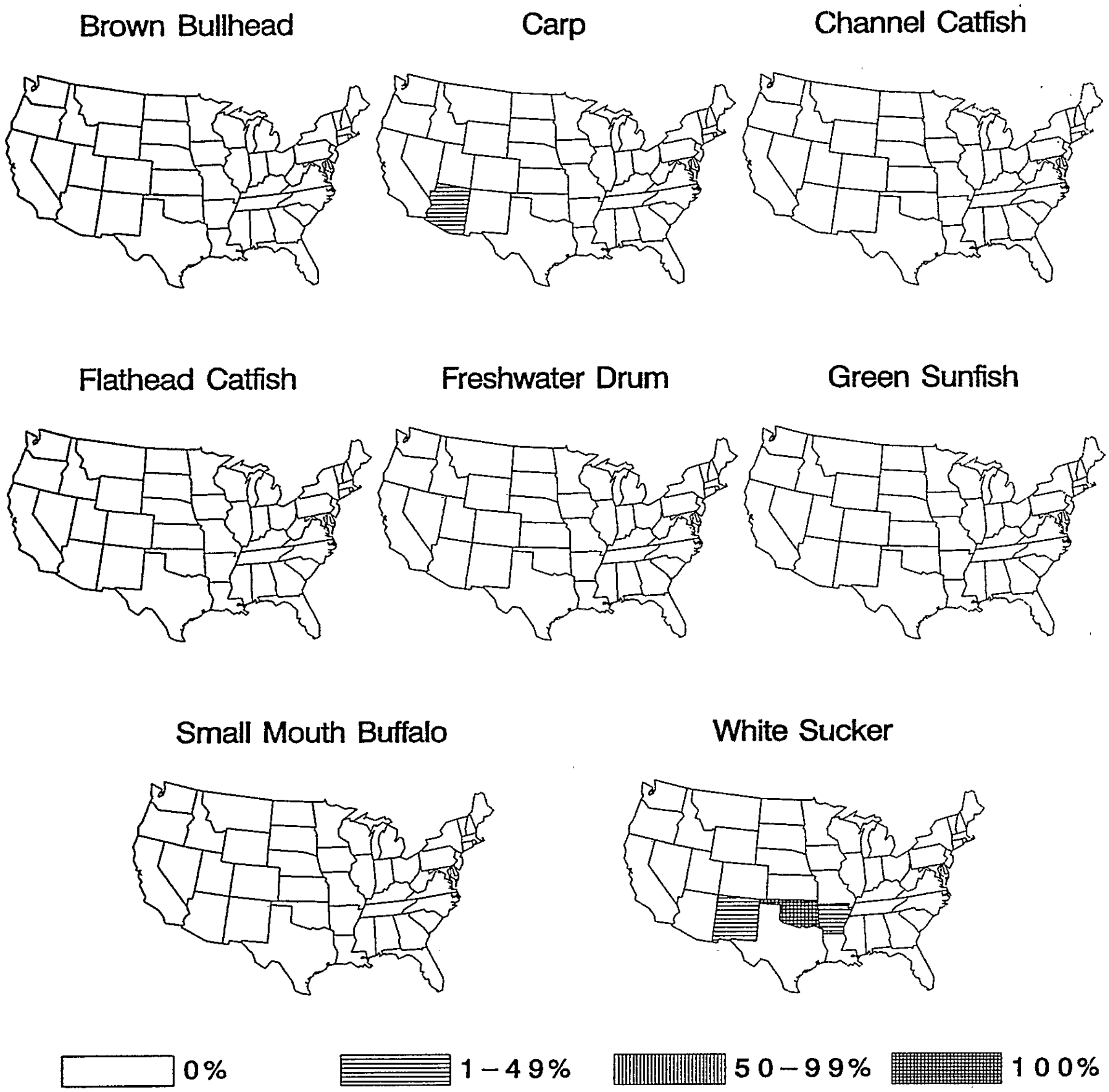


Exhibit 2-30
Loss of Habitat for Rough Fish (GF1)



As can be seen from these exhibits, expected losses of cold-water fish are significant with all four GCMs. Losses (expressed as a percent of original fishable acres) are generally greatest along the southern border of a species' natural range, where baseline temperatures are closest to thermal tolerances. Cold-water species are most affected, but significant losses are also predicted for the cool-water guild, and for individual members (e.g., crappie, rock bass, smallmouth bass and white sucker) of warm-water and rough guilds.

Exhibit 2-27 shows the effects of warming for each of the fish guilds as projected by the GFDL. Cold- and cool-water fishing are hurt the most as eight states lose all of the cold- or cool-water fishing available to them. In addition, over fifty percent of cold- and cool-water fishing are lost in fifteen states. Sixteen other states show a cold- or cool-water loss to a lesser degree. Significant cold-water guild losses occur throughout their range. Conversely, cool-water guild losses are concentrated in the southern sections of their habitable range. Specific losses in the warm and rough water guilds were light except for the elimination of: black crappie in Oklahoma and Texas; smallmouth bass in Oklahoma and Arkansas; and white sucker in Arkansas. Warming projected by the UKM model (Appendix D) is similar to that in the GFDL model. Cold-water guild losses are in the same range while cool-water guild losses are slightly more evident in the UKM. Specifically, cold- and cool-water guilds are eliminated in nine states while seventeen others lose over 50 percent of their cold- and cool-water fishing capacity. Under the UKM model cold-water fish are lost across their natural ranges and cool-water fish are often lost in the southern to middle sections of their ranges. Marginal to significant losses in Wisconsin, Illinois, and Iowa of cool-water fish (all but the yellow perch in Wisconsin) sets the UKM apart from the GFDL. Warm water species are lightly effected in most cases but black crappie is reduced 50 percent or more in five states (white crappie in 4) and smallmouth bass have a 50 percent or higher loss in four states.

The OSU model predicts warming that has a slightly greater effect on cold-water fish than the GFDL and UKMO models but has less of an effect on the cool guild (Appendix C). Cold- and cool-water guilds are completely eliminated in ten states. Over fifty percent of the cold- and cool-water guilds are eradicated in fourteen states. Within natural ranges losses happen throughout the cold-water fish species. Cool-water fish losses are less than cold throughout species' natural ranges except walleye which is eliminated in Kansas, Oklahoma, Arkansas, and Mississippi. Specific losses in the warm-water guild are masked at the guild level by available substitutes within the individual states.

Warming predicted by the GISS model has the lowest effect of all of the GCMs, eliminating cold- and cool-water guilds in five states (Appendix B). Cold and cool-water guilds are reduced over 50 percent in a total of eleven states. Warm and rough water guild losses are insignificant and mask most specific fish species losses. Specific cold-water species losses occur throughout their ranges, aside from a handful of unaffected states spread throughout. A lack of substitutability causes the specific walleye losses to almost mirror the overall cool guild losses.

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3. AN ECONOMIC ASSESSMENT OF RECREATIONAL FISHING IMPACTS

3.1 INTRODUCTION

Climate change could have a tremendous effect on the availability of different fish species in the rivers and streams of the continental U.S., as the previous chapter demonstrated. These physical impacts could result in substantial disruptions in an important American pastime, recreational fishing. As an earlier study showed, the U.S. has a lot at stake in recreational fishing (Michaels et al., 1992). Nearly a billion person-days were devoted to recreational fishing in 1985. Nearly 30 percent of these were associated with cold-water and anadromous fishing and more than 40 percent to warm-water and rough fishing. This activity could be worth more than $30 billion annually in terms of the consumer surplus it generates. While recreational fishing does not represent fully the economic significance of climate change impacts on freshwater fish, an economic assessment focused on recreational fishing does capture an important link between ecosystems vulnerable to climate change and human well-being.

Establishing the link between the availability of different recreational fish species and its impact on economic welfare requires an understanding of the determinants of recreational fishing behavior. The kind of fish that can be caught, the chances of success, the quality of the fishing experience itself, and proximity are a few facets of angling that have been commonly noted as important. These and other such factors determine which people will fish, what species they target, where they go, how often they go, and what the experience is worth to them. On a national scale, some of this behavior has been quantified by the Surveys of Fishing, Hunting, and Wildlife-Associated Recreation conducted about every five years by the U.S. Fish and Wildlife Service. These surveys provide national estimates of anglers' socioeconomic characteristics, species targeted, frequency of activity, and the value of different types of fishing (trout and bass). It is a greater challenge however to characterize where anglers go, not in terms of location but in terms of what each fishing designation offers with regard to the chances for success and the quality of the fishing experience. Since these factors can vary dramatically from one location to the next, a potential angler has a host of different sites from which to choose. The likelihood of fishing at a given site and the value attached to that experience will vary from site to site and both of these will vary from one potential angler to the next. Conducting an economic study of recreational fishing behavior is an information-intensive undertaking if all of these factors are to be addressed for a number of sites.

Compounding the difficulty in the current study is the necessity of saying how these factors will change as the result of changes in the ecosystem supporting the fish. This particular challenge has been addressed in the current study by assessing the habitability of approximately 900 locations around the country for different recreational fish species before and after climate change. This approach simplifies the link between the climate-change induced ecosystem changes and changes in recreational fishing behavior. If a certain species is no longer available in a given location, it is assumed that the value of fishing for that species reduces to zero. Other losses affecting recreational fishing, such as reduced productivity, could also be anticipated from climate change but these impacts present considerable difficulties for both a risk and an economic assessment. In this regard, the current effort provides conservative estimates of the potential damages to recreational fishing.

This difficulty resolved, the challenge of translating changes in fish species survivability at virtually every single fishing location in the continental U.S. into estimates of changes in recreational fishing behavior is enormous. It is beyond the scope of the current effort to implement a study that characterizes the array of alternative fishing opportunities available around the country to the entire population of potential anglers. As a matter of fact, such an effort has been beyond the scope of every other recreational fishing study to date.[1] Instead of a highly site-specific approach, this study focuses on a characterization of fishing opportunities at a higher level of aggregation, that of each state, and on the characteristics of the anglers themselves.

3.2 ECONOMIC MODEL

The economic model adapted for this study is based upon a framework developed by Vaughan and Russell (1982). Their framework was constructed to estimate how fishing behavior, ultimately described in terms of days spent fishing, would change as a function of expanding very specific types of fishing (cold-water, warm-water, and rough fishing).[2] By assigning a value to a day of each type of fishing and by estimating how the available acreage of each type would change with water quality improvements, Vaughan and Russell (1982) were able to estimate the national benefits of water quality improvements to different types of recreational fishing. By differentiating fish species primarily in terms of thermal conditions, their model lends itself immediately to adaptation to an economic assessment of climate change.[3]

Vaughan and Russell emphasize three issues in their evaluation of national recreational fishing benefits: (1) the mechanisms by which control of water pollution discharges create

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[1] EPA and other federal agencies have initiated such an effort, which is not expected to bear fruit for a year or so.

[2] Selected examples of each fishing type include trout and salmon (cold-water); bass, muskellunge, sauger, and northern pike (warm-water game fish and panfish), and carp and catfish (rough).

[3] Vaughan and Russell define their three fish types both by water quality (dissolved oxygen) and temperature requirements, but each fish type also has a unique temperature range. Cold-water fish are assumed to exist in waters less than or equal to 18°C, warm-water fish in waters above 18°C and below 32°C, and rough fish from 32°C to 34°C.

benefits for recreational fishermen; (2) the tools and data necessary to assess these mechanisms; and (3) the special difficulties of obtaining national benefits estimates. Many of these same issues are germane to the analysis of global climate change effects in national recreational benefits. Global climate change will affect the temperature of surface waters throughout the United States, and the sensitivity of fish populations to anticipated temperature shifts will vary considerably, as described in Chapter 2. Dramatic shifts in temperature can result in species composition shifts as well as changes in the number of fishable acres or sites within the United States. Temperature changes will have two effects: changing fish species composition and changing the distribution of acreage supportable for different types of fishing activities.

Vaughan and Russell model the effects of pollution control on individuals, each facing a cross section of available sites of varying quality. The authors couch the analysis in terms of the household production framework. It is envisioned that consumers produce service flows using technology, time, and purchased inputs. Changes in water quality are linked with changes in the supply curve such that assessments of patterns in the production of recreational fishing days might be estimated using reduced form equations.

The reduced form model treats changes in site quality using a three-stage estimation process. The first stage predicts the probability of being a fisherman. The second stage predicts the probability of doing some cold-water, warm-water, and rough fishing. The third stage predicts the average days per angler devoted to cold-water, warm-water, and rough fishing. Each of these stages use information on the availability of each fish. Availability is quantified in terms of acres.[4] Each acre of fishable freshwater is uniquely assigned to cold-water, warm-water, and rough fishing. This assignment is made according to the "best use" that a given water body will allow. It is assumed that anglers prefer cold-water fishing to warm-water fishing and both of these to rough fishing. Therefore, if water quality (dissolved oxygen) and temperature conditions allow, an acre is counted as available for cold-water fishing. Otherwise, if not suitable for cold-water but still suitable for warm-water fish, the acre is assigned to warm-water fishing. By a similar process of elimination, the remaining acres are assigned to rough fishing or designated as unfishable. This approach allows for the far-reaching impacts of changes in water quality to be addressed in terms of changes in quantity rather than as complex adjustments for each individual in relation to distances and travel costs.

This approach estimates changes in participation days and then values these changes using a unit value approach. In short, this reduces to multiplying the estimated changes in warm-water, cold-water, and rough fishing by relevant activity-day values. Although theoretically the appropriate value for changes in the number of recreational days are the marginal values, such

[4]One reviewer of this study suggested that stream-fishing behavior may be more of a function of stream length than acreage. For narrow streams, this distinction may not be meaningful. For larger streams, the size of the measurement error involved is unknown. Consequently, this study adhered to Vaughan and Russell's original specification using acres.

values are rarely observable. It is almost impossible to infer where on the range of equilibria individuals fall before and after the proposed policy scenarios. An average measure of consumer surplus is often adopted as an alternative.

3.3 ALTERNATIVES TO THE SELECTED MODELLING APPROACH

In the past decade, there have been no new published studies focused on all four types of recreational fishing from a national perspective. The economic modelling of recreational fishing behavior has taken a very site-specific frame of reference. The overview of recreational fishing studies provided in Appendix G shows how site-specific and, at times, fish-specific studies have been. Even when multiple sites are modelled, their geographic scope is often limited. This orientation has probably been influenced by a demand for studies at the sub-national level. Many of the studies have certainly supported policy analysis for important issues on a site-specific, regional, and state level. The tendency to construct such models is also heavily influenced by the prevailing view in the environmental economics profession that better definition of alternative fishing sites, especially in terms of environmental quality, is an important element in describing recreational fishing behavior.

Understandably, given the large demand for economic analysis to support policy analysis at the national level, environmental economists have been groping for substitutes that can be built upon the existing body of site-specific literature. The primary candidate has been the general process of "benefits transfer" through which the estimates of one or more studies can be applied to one or more new locations that have not been analyzed to the same degree but which are similar "enough" that making the inference of economic valuation this way seems reasonable. For several reasons, this approach is not suitable for the existing body of recreational fishing studies.

When dealing with changes in site quality such as those imposed by global climate change dynamics, several important connections must be established. First, the characteristics that matter to people must be designated and mechanisms of how to measure these characteristics must be assigned. Second, changes in the quality of many sites must be tied with demand functions so that changes in site quality will result in demand shifts. On this second point, travel cost models, which have been commonly used to value recreational fishing experiences, seem to be inadequate. While versions of the travel cost model can capture the influence of site quality, they fail when changes occur at multiple sites because these models do not characterize substitutability among sites (Freeman, 1993a).

Another modelling alternative—discrete choice, or random utility, models—is more promising. They can be constructed to address differences in quality and substitutability among sites. The difficulty in drawing upon this body of work is that the current studies are too few and provide only limited geographic coverage. Furthermore, no widely accepted benefits transfer protocol has been established to construct a national model of fishing behavior that is based upon these studies and that is linked to measures of environmental quality.

One final alternative to adapting the framework of Vaughan and Russell is a national approach based on contingent valuation. This approach would entail using contingent valuation information on the incremental benefits of water quality improvements necessary to attain fishability, such as those compiled by Carson and Mitchell (1993). It, like the approach of Vaughan and Russell, has already been used to estimate the national benefits of controlling water pollution under the Clean Water Act. Both approaches attempt to capture the recreational fishing value of clean water but they differ substantially in what they measure. Vaughan and Russell attempt to do so by making inferences from observed recreational fishing behavior and the availability of different types of fishing opportunities in the U.S. In contrast, the work of Carson and Mitchell does not consider specific attributes of fishing. They estimate, instead, the value of converting a large amount of water, on a national basis, to fishable; by this they meant that the water was clean enough that "game fish like bass can live in it" (Carson and Mitchell, 1993, p. 2447). This kind of measurement is potentially useful in a study of climate change and recreational fishing but it has limited applicability. For example, the thermal model in the current study calculates the amount of national freshwater that is rendered unfishable because temperatures become too high for any recreational fish species. The estimated amounts are seldom greater than 0.5 percent in any of the climate-change scenarios. Even a definition of fishability based on habitability for game fish, such as trout or bass, results in only slightly larger impacts. Estimated increases in non-game fish habitat range from 1 percent to 3 percent. Because it does not relate well to the redistribution of fishing likely to occur with climate change, a national approach based on the existing contingent valuation of fishability does not appear to be fruitful.

3.4 IMPLEMENTATION OF THE ECONOMIC MODEL

Following the design employed by Vaughan and Russell (1982), the economic model is a reduced form model that characterizes the repercussions of changes in water temperature on recreational fishing behavior using a three stage-estimation process. The first stage describes the probability of general fishing participation. The second stage predicts the conditional probability of doing one or some combination of cold-water, cool-water/warm-water, and rough fishing activities. The third stage characterizes the average number of person days devoted to cold-water, cool-water/warm-water, and rough fishing per year.

The thermal and economic models are constructed to represent recreational fishing in the 48 contiguous states. Accordingly, the implementation of the economic model requires tremendous amounts of data. While consistent and comprehensive data on the general population are available, similar data are not readily available for categorical angler and recreation populations. Because of such significant information constraints, the economic model does not calculate coefficients for each of these stages. Rather, the economic model uses coefficients derived by Vaughan and Russell (1982) in their national analysis of water pollution controls. In the implementation process, the economic model relies on information from several sources, including input data provided by the thermal model that characterizes the recreational fishing opportunities, input data acquired from empirical sources describing the relevant populations, and estimated coefficients communicating the likelihood of different behavioral adjustments. Input data are maintained at a state level; and, when possible, inputs to the model have been updated to reflect current national and angler population characteristics (i.e., 1990-1991). Combining input values with the Vaughan and Russell coefficients, the economic model produces average estimates of the probability of fishing by category, the number of anglers by category, and the number of fishing days by category. These outputs are estimated for each of the scenarios and ultimately account for the variation in the proposed benefits/damages estimates.

The results of the previous chapter illustrated how temperature changes that occur because of climate change can significantly alter the availability of different fish species. Fish species that have lower thermal tolerances can lose their habitats. From an ecological perspective, these losses may or may not be offset by gains in the abundance of fish that are more tolerant of higher temperatures. Such an outcome was not specifically modelled. Instead, the thermal modelling was organized to coincide with the perspective taken in the economic model presented here. This model assumes that each fishable acre is uniquely assigned to the best use allowed by thermal conditions. The ordering of fish guilds and thermal tolerances approximately coincide. Cold-water fish are preferred to cool-water fish, which are preferred to warm-water ones. The fourth category, rough fish, are the least preferred and tend to have high thermal tolerances. A fifth category, "none," is added as a residual to reflect unfishable acres in the baseline and the additional acres that become unfishable because temperature increases render them uninhabitable for any recreational fish.

The mutually exclusive assignment of freshwater acreage to the four fish guilds (cold, cool, warm, rough) implies a narrow view of the fishing opportunities available to U.S. anglers. Because each fishable acre has a unique assignment (cold, cool, warm, or rough), this assumption implies, for example, that a cold-water acre will be visited by anglers pursuing cold-water fish only, and not by anglers seeking fish in other guilds. This assumption could decrease the size of the net damages estimated in the economic model. If it is true that, say, cold- and warm-water fishing are not done at a given water body and if this water body converts from a cold-water "best use" to a warm-water best use as the result of climate change, then the estimated net damages are not biased. There are however two cases where the estimated net damages could be understated. In the first case, if both cold- and warm-water fishing are taking place before and only warm-water fishing afterwards, the net damages could be underestimated. In the second case, if only cold-water fishing is taking place before climate change and it is infeasible or unlikely that warm-water fishing will take place after climate change, net damages could again be underestimated. The extent of the downward bias is the same for both these cases assuming that the values of cold- and warm-water fishing hold constant.[5]

The original developers of the economic model adapted in this study support this assumption by pointing to the results of studies on angler preferences (Vaughan and Russell, 1982, p. 38), which was the basis for the preference ordering used here. Vaughan and Russell restate the assumption in terms of supply rather than demand. "[T]he state fishery manager will ensure that [the water body] is supporting whichever type is higher on a scale of preference broadly accepted by both fisherman and fishery management professionals." The view taken in the current study is that the validity of the assumption is better verified through empirical information on the likelihood of more than one type of angling on specific streams and rivers before and after climate change. Information from the 1985 Survey of Fishing, Hunting, and Wildlife-Associated Recreation supports the "best-use" assumption at least for parts of the U.S. In the region including the states of Colorado, Montana, North Dakota, South Dakota, and Wyoming, the number of person-days spent cold-water fishing is almost four times greater than the number spent warm-water or rough fishing.[6] This outcome occurs despite the fact that these states are considered habitable by warm-water and rough fish.

It is more difficult to determine the likelihood of joint freshwater angling in other states, especially if only a part of a state's waters have been deemed habitable by cold- and cool-water fish. In such cases, it is possible that cold- and warm-water fishing take place in different parts of a given state. This pattern of fishing is consistent with the mutually exclusive classification of waters used to implement the "best-use" assumption. In the current effort, it has not been

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[5] An example may help clarify this discussion. Assume that C and W are the values of cold-water and warm-water fishing respectively on a given stream. If both cold- and warm-water fishing are feasible but only cold-water fishing takes place, then the value of fishing before climate change is C and afterwards is at best W. The difference is C-W. In this case, there is no downward bias attributable to the "best use" assumption. If however both cold- and warm-water fishing are possible before and only warm-water is possible after climate change, the net damages are (C+W)-W = C rather than C-W. The damages are also C if only cold-water fishing is possible before and no fishing is possible afterwards. Finally, it is possible that C will rise as the supply of cold-water fishing opportunities falls (to C′) and that W will fall (to W′) if the supply of warm-water fishing opportunities rise. In this case, (C′-W′) will exceed (C-W). In all three cases, the estimated net damages (C-W) would be biased downwards.

[6] This comparison is based upon calculations made from state-specific data from the 1985 Survey of Fishing, Hunting, and Wildlife-Associated Recreation that was categorized into cold-water and warm-water categories in Michaels et al., 1992 (Appendix A1). Approximately 20 million person-days are spent on cold-water fishing in these states, exclusive of salmon fishing, versus approximately 5.5 million person-days spent warm-water fishing.

possible to make a state-by-state determination of the appropriateness of the "best-use" assumption. Instead, the issue is investigated further through a sensitivity analysis.

Changes in the distribution of the "best-use" acreages drive the simulation of changes in recreational fishing behavior. The economic model is specified with the total acreage of the freshwater lakes, impoundments, rivers, and streams as assigned mutually exclusively to cold-, cool-, warm-water, and rough fishing. Total acreage in the baseline was adopted from Vaughan and Russell (1982), which provides fishable cold-, cool-/warm-water, and rough acreage for each state. Because Abt Associates' thermal model is constructed to evaluate rivers and streams only, it was necessary to apportion the total acreage into two parts—rivers and streams and lakes and impoundments. Information from the 1985 Survey of Fishing, Hunting, and Wildlife-Associated Recreation on fishing days by location was used to apportion a state's total fishable acreage into lake and impoundment acreage and river and stream acreage. River and stream acreage in each state was further subdivided into cold-, cool-, warm-water, and rough portions based on estimates from the thermal model. Since no changes in the allocation of lakes and impoundment acreage was estimated, determining the baseline allocation of lake and impoundment acreage is sufficient to specify the economic model. However, because the state acreage estimates from Vaughan and Russell aggregate cool- and warm-water fishing, whereas the Abt Associates' thermal model separates the two guilds, total warm- and cool-water acreage in each state had to be split into warm- and cool-water portions.

This split was based on one of two rules. First, the split between cool- and warm-water acreage estimated for rivers and streams in each state in the thermal model became the basis for apportioning total warm-/cool-water acreage in that state, if the thermal model assigns any fishable acreage in that state to warm- or cool-water fishing. If not, the second rule was to assign warm-/cool-water acres in the state to the two fishing types according to the number of cool- and warm-water fishing days estimated for the state. These estimates were derived from the 1985 Survey of Fishing, Hunting, and Wildlife-Associated Recreation data in Michaels et al., (1992). Exhibit 3-1 presents the assignment of total freshwater acres to the four fishing types or to none (for unfishable acres) in the baseline and for main specifications of the six GCM models evaluated in this study.

With the exception of changes in river and stream acreages, inputs to the economic model approximately represent the state of the world in the late 1980's or early 1990's. In particular, socioeconomic data, such as population and average income, used to specify the model were drawn from the 1990 U.S. Census. Rather than introduce simulations in population and income growth, these conditions were assumed to be the status quo with and without climate change. Growth in population and income could by themselves have a tremendous effect on the amount and type of fishing occurring in the baseline year of analysis, which is at least 56 years hence (2050) and in some cases as much as 106 years away (2100).

Although it is known that increases in population and income result in more recreational fishing, it is unknown what bias is introduced by the exclusion of population and income growth from the modelling at this stage of development. If such growth were to be incorporated, it would be necessary to adjust the relative values placed on cold-, cool-, warm-water, and rough fishing. The current analysis holds these constant under the scenarios, with and without climate change, because little is known about how these relative values can change with the reallocation of freshwater acreage as the result of climate change. Clearly this reallocation will change the relative values, but it is anticipated that population and income growth could have an even larger impact. Their impact is magnified because they are exponential and could easily double or triple the estimated amount of fishing in the 2050 and 2100 baseline years.

Simultaneous with this growth there could be a significant restructuring of observed fishing preferences and the relative values of cold-, cool-, warm-water, and rough fishing. The relative value of cold-water fishing, the most vulnerable to climate change, is probably also the most sensitive to income growth, thereby compounding any effects on estimated impacts that are linked to the growth in income. By contrast, the estimated changes in the allocation of fish acreages attributable to climate change are, while substantial, still equivalent to less than a 100 percent change in the number of fishing days. At this initial stage of analysis, income and population growth are held constant in order to reduce the number of compounding uncertainties while a feasible set of model facets is tested. In this respect, the current analysis should be interpreted as an initial experiment to gauge the general size of the recreational fishing impacts and the sensitivity of the economic model to a finite set of alternative specifications.[7]

The link between behavioral responses of recreational fishing and thermal changes is established in the structure of the three stages of the economic model. The thermal responses of the climate change scenarios shift the availability of types of fishing opportunities. These transitions are expressed in movements in acreage from one best-use category to another. As acreage shifts occur, the input values to each of the three stages change; and it is these adaptations that explain the different numbers and compositions of fishing days associated with each of the climate scenarios. The implications of the changes in best-use acreage are made clearer by understanding the different stages of the estimation process. Brief descriptions of each of the modelling stages follow. Throughout the discussion, emphasis is awarded to those variables that are assumed to be changing across the global climate change scenarios.

[7]This analysis, like any other analysis of the effects of climate change, is bound by current understanding of tastes and preferences. One reviewer of this study has suggested that certain fishing activities, such as Pacific salmon and steelhead fishing, may experience dramatically increasing relative values in coming decades. If true for cold-water fishing in general, then the actual damages would be much higher than those estimated in this study. The decision to adhere to constant consumer surplus estimates in this study underscores how much more could have been done to increase the estimated damages. Instead, for the sake of better credibility, the authors chose to adhere to the status quo of fishing values which results in a conservative range of damage estimates.

Exhibit 3-1
Distribution of Acreage by Fishing Type,
Baseline and GCM Simulations

ACRES

Scenario	Total	Fishable	Cold	Cool	Warm	Rough	None
BASELINE	31,670,834	31,670,834	7,358,164	13,597,718	6,670,872	4,044,080	0
Share	100.00%	100.00%	23.23%	42.93%	21.06%	12.77%	0.00%
GF1	31,670,834	31,655,519	4,821,052	14,447,541	7,976,645	4,410,281	15,315
Share	100.00%	99.95%	15.22%	45.62%	25.19%	13.93%	0.05%
GI1	31,670,834	31,664,273	5,392,621	14,343,256	7,546,711	4,381,685	6,561
Share	100.00%	99.98%	17.03%	45.29%	23.83%	13.84%	0.02%
OS1	31,670,834	31,655,519	5,083,136	14,073,906	8,145,845	4,352,632	15,315
Share	100.00%	99.95%	16.05%	44.44%	25.72%	13.74%	0.05%
UK1	31,670,834	31,604,041	4,320,346	14,295,669	8,197,710	4,790,316	66,793
Share	100.00%	99.79%	13.64%	45.14%	25.88%	15.13%	0.21%
TR1	31,670,834	31,664,273	5,948,744	13,506,880	7,803,841	4,404,808	6,561
Share	100.00%	99.98%	18.78%	42.65%	24.64%	13.91%	0.02%
TR2	31,670,834	31,655,519	4,037,011	14,439,266	8,324,890	4,854,351	15,315
Share	100.00%	99.95%	12.75%	45.59%	26.29%	15.33%	0.05%

The first stage calculates the probability of general fishing participation(P_{GF}). Exhibit 3-2 presents the variables used in the estimation of the first stage and notes the source of each variable. The variables reflect socioeconomic characteristics as well as broad recreational fishing opportunities. With the exception of fishable acreage per capita, the input values for this calculation are estimated using the 1992 Statistical Abstract of the United States (U.S. Department of Commerce 1992). Estimates of the fishable acreage per capita per state are produced by the thermal and economic models using U.S. population estimates and the modified Vaughan and Russell (1982) baseline acreage data. The socioeconomic characteristics do not change across scenarios. Conversely, the fishable acreage variable changes considerably across scenarios with the changes in temperature. The input values are combined with the Vaughan and Russell coefficients (1982, Table 3-6, Reduced Model I) to derive the general fishing participation probability (P_{GF}). Because the coefficients were estimated using a logit specification, the final general fishing participation probability is calculated as follows: $P_{GF} = 1/(1+e^{-\Sigma\{\beta * X\}}$ where the βs are the estimated coefficients and the Xs are the estimated input values.

The second stage calculates the conditional probability of participation by fishing category ($P_{FC} \mid P_{GF}$). For the purposes of this analysis, the economic model distinguishes fifteen mutually exclusive fishing categories. Each of these fifteen categories are some combination of the following types of fishing activity: T (cold-water); BP (cool-water/warm-water); R (rough); and S (salt or Great Lakes). The fifteen categories are as follows: (1) T; (2) BP; (3) R; (4) S; (5) TBP; (6) TR; (7) TS; (8) BPR; (9) BPS; (10) RS; (11) TBPR; (12) TBPS; (13) TRS; (14) BPRS; and (15) TBPRS. The economic model calculates the conditional probability for each category and then aggregates these probabilities according to designations for cold, cool/warm, and rough fishing activities. For example, any category including T is counted as cold-water fishing, and similarly, all categories with BP and R are treated as warm/cool and rough fishing respectively.

Exhibit 3-3 presents the variables used in each of the estimations by category and notes the source of each variable. Similar to those used in the first stage, the input variables reflect socioeconomic characteristics and recreational fishing opportunities. In this stage, however, the data becomes more activity specific. The socioeconomic data represent the angler population and the catch rates and fishable acreage information are organized by thermal acreage category. The input variables used in the second stage include the average age and annual income of U.S. anglers, the percentage of female, metropolitan-residing, and coastal-residing anglers, the average numbers of cold-water fish, cool-water/warm-water fish, and rough fish caught per day, and the ratios of warm-water fishing acreage and rough fishing acreage to total fishing acreage. The input values for the average annual income, age, gender, and percentages in metropolitan areas and along marine coastlines are estimated using the 1991 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (US DOI, 1993). The average catch rates for cold-water, cool-water/warm-water, and rough fishing days were derived using Vaughan and Russell regional data (1982, Table 4-4). A weighted average is calculated based on the regional

Exhibit 3-2
First Stage: Predicting the Probability of General Fishing Participation[1]

Variable	Source
Intercept	Not applicable
Age	US Department of Commerce (1992)
Age-squared	US Department of Commerce (1992)
Gender (female)	US Department of Commerce (1992)
Metropolitan area	US Department of Commerce (1992)
Western region	US Department of Commerce (1992)
Central region	US Department of Commerce (1992)
Southern region	US Department of Commerce (1992)
Fishable acreage per capita by state	Abt economic and thermal models
Average income per household	US Department of Commerce (1992)
Head of household	US Department of Commerce (1992)
Coastal state	US Department of Commerce (1992)

[1] The data employed in the first stage represent the national population in 1990 and recreational fishing opportunities.

averages with the regional percentages of U.S. anglers serving as the weights. The fishable acreage ratios are gleaned by the economic and thermal models. In practice, the socioeconomic characteristics are held constant and the acreage ratios are permitted to vary across the climate scenarios. The input values are combined with the coefficient estimates provided by Vaughan and Russell (1982, Table 4-8) for each fishing category. Since the coefficients were estimated using a weighted least squares approach, the conditional categorical probabilities are calculated as follows: $P_{FC} \mid P_{GF} = \Sigma\, \beta^{*}X$ where the βs are the estimated coefficients and the Xs are the estimated input values. The conditional probabilities of participation are estimated for all fifteen categories. These probabilities are then aggregated to predict participation probabilities for the categories of cold-water (P_{CDF}), cool-water/warm-water (P_{CWF}), and rough fishing (P_{RF}).

The third stage calculates the average number of days per year devoted to cold-water (D_{CDF}), cool-water/warm-water (D_{CWF}), and rough fishing (D_R). Separate calculations are completed for each of these three fishing activities. Exhibit 3-4 presents the variables used to predict the number of fishing days. The variables include socioeconomic characteristics and

Exhibit 3-3
Second Stage: Predicting the Probability of Participation by Fishing Category[1]

Variable	Source
Intercept	Not Applicable
Average income per household	US DOI (1993)
Age	US DOI (1993)
Age-squared	US DOI (1993)
Gender (female)	US DOI (1993)
Metropolitan area	US DOI (1993)
Coastal area	US DOI (1993)
Average number of cold-water game fish caught per fishing day	Vaughan and Russell (1982)
Average number of cool-water and warm-water gamefish/panfish caught per fishing day	Vaughan and Russell (1982)
Average number of roughfish caught per fishing day	Vaughan and Russell (1982)
Ratio of cool-water and warm-water fishing acreage to total fishing acreage	Abt economic and thermal models
Ratio of rough fishing acreage to total fishing acreage	Abt economic and thermal models

[1] The input variables employed in the second stage represent U.S. anglers and thermal categories of recreational fishing. Outputs from the model are derived for 15 mutually exclusive categories using unique sets of category coefficients. These category probabilities are then aggregated to reflect cold-water, cool-water and warm-water, and rough fishing participation estimates.

descriptions of recreational fishing opportunities. Socioeconomic variables include average age and income by angler type and the percentages of female, metropolitan-residing, and coastal-residing individuals by angler type. The recreational fishing opportunity variables include the average number of cold-water fish caught per day, cold-water fishing acreage per capita, average number of cool-water/warm-water fish caught per day, warm-water fishing acreage per capita, average number of rough fish caught per day, and rough fishing acreage per capita. The majority of the input values used in this stage of the estimation are taken from Vaughan and Russell (1982, Table 4-12) because of the limited socioeconomic information available on a national basis for anglers by fishing type or category. Implementing the model, most of the socioeconomic and recreational fishing characteristics are held constant across the scenarios. The fishable acreage estimates per capita are exceptions to the rule, as these vary with each climate scenario. The input values are combined with the Vaughan and Russell (1982, Table 4-12, Unrestricted Model) coefficients to derive three estimates of average person-days by fishing activity. Because the coefficients are estimated using a weighted least squares approach, the average number of fishing days per person are calculated as follows: $D_{CDF} = \Sigma\ \beta * X$ where the βs are the estimated coefficients and the Xs are the estimated input values. The average days are estimated for the categories of cold-water (D_{CDF}), cool-water/warm-water (D_{CWF}), and rough fishing (D_{RF}).

The output of the economic model combines information from all three stages of the estimation process. To estimate the number of fishing days for one activity such as cold-water fishing, the probability of general fishing participation (i.e., the output of Stage 1) is first multiplied by the conditional probability of fishing for the category of interest (i.e., the output of Stage 2). This probability is then combined with the estimate of the average number of days devoted to the fishing activity per year (i.e., the output of Stage 3) and an appropriate population estimate (i.e., Bureau of Census 1992) to derive the total number of fishing days. For example, the total number of cold-water fishing days predicted under one scenario would be calculated as follows: $TD_{CDF} = P_{GF} * P_{CDF} * D_{CDF} *$ POPULATION. For each run of the economic model, this procedure is adapted to estimate the total number of cold-water, cool/warm-water, and rough fishing days (TD_{CDF}, TD_{CLF}, TD_{WMF}, and TD_{RF}). In contrast to Vaughan and Russell (1982), the economic model distinguishes cool-water and warm-water fishing activities. In doing so, it is assumed that the average number of fishing days per person is the same for cool-water and warm-water fishing and that the ratio of the total number of cool-water fishing days and warm-water fishing days is equal to the ratio of the best-use acreage estimates for cool-water and warm-water fishing.

After designating the behavioral responses with the results of the three stages, the economic model values the predicted behavioral responses. The welfare or valuation analysis of the economic model is couched in relative terms, with values being placed on the changes in the number of fishing days relative to baseline estimates (CTD_{CDF}, CTD_{CLF}, CTD_{WMF}, and CTD_{RF}). A discussion of the definition and valuation of recreational fishing days follows.

A recreational fishing day is commonly known as one person on-site for any part of a calendar day (Walsh et al., 1992). Economists have been deriving fishing day values for over

Exhibit 3-4
Predicting the Number of Person Days Per Year Devoted to Fishing by Guild[1]

Variable	Source
Intercept	Not applicable
Age	Vaughan and Russell (1982)
Preference intensity for fishing dummy	Vaughan and Russell (1982)
Age-squared	Vaughan and Russell (1982)
Gender (female)	Vaughan and Russell (1982)
Metropolitan area	Vaughan and Russell (1982)
Average income per household	Vaughan and Russell (1982)
Coastal area	Vaughan and Russell (1982)
Average number of cold-water gamefish caught per day	Vaughan and Russell (1982)
Cold-water fishing acreage per capita	Abt economic and thermal models
Average number of warm-water gamefish/panfish caught per day	Vaughan and Russell (1982)
Warm-water fishing acreage per capita	Abt economic and thermal models
Average number of rough fish caught per day	Vaughan and Russell (1982)
Rough fishing acreage per capita	Abt economic and thermal models

[1] The input variables employed in the third stage represent specific types of anglers and specific types of recreational fishing opportunities. Separate predictions are derived for cold-water, cool-water/warm-water, and rough fishing.

twenty-five years. A number of recent reviews of empirical research efforts have been published (American Fisheries Society, 1993; Freeman 1993b, Walsh et al., 1992; Walsh et al., 1990; and Sorg et al., 1984). Several of these review studies have prompted related lines of research such as the comparison of values from different studies (i.e., Smith and Kaoru 1990; Kling 1988; Walsh et al., 1990; 1992) and the transferring of values across geographical areas, populations, and time (i.e., Atkinson et al., 1992, and Deck et al., 1992).

Recreational fishing shares two common features with other natural resource recreational service flows. First, the value of a recreational fishing day varies with the quality of the natural resource, including the water quality and type and abundance of fish stock. Secondly, access and rules governing recreational fishing behavior are not typically determined by market forces. For example, observed fishing behavior in the United States suggests individuals on average prefer saltwater fishing to warm-water fishing, trout fishing to catfish fishing, and stream fishing to lake fishing. Observed behavioral patterns also imply that few recreationists actually pay for the opportunity to fish. Together, these two features allude to the necessity of relying on inferred estimates of the value of a recreational fishing day. In the context of the proposed global climate change scenarios, values must be derived that are associated with a large variety of waters, fishing activities, and fish species and that reflect the preferences of a wide array of individuals.

The economic model estimates changes in fishing days for cold-water, cool-water, warm-water, and rough fishing (V_{CDF}, V_{CLF}, V_{WMF}, and V_{RF}) and then values these changes using a unit value approach. In short, this reduces to multiplying the estimated changes in cold-water, cool-water, warm-water, and rough fishing days by the designated fishing day value for each activity (i.e., dollar value = $V_{CDF} * CTD_{CDF}$). Although theoretically the appropriate value for changes in the number of recreational days are the marginal values, such values are rarely observable. As a result, an average measure of consumer surplus is adopted as an alternative measure of value. Exhibit 3-5 presents summary statistics of average consumer surplus values derived by Walsh et al., 1992 for cold-water fishing, anadromous fishing, warm-water fishing, and saltwater fishing. These values were calculated as part of an empirical review of recreational fishing day values. The values represent the dollar amount individuals are willing to pay over and above their current expenditures to ensure the continued availability of the opportunity to use recreational fishing resources (Walsh et al., 1992). The values displayed in Exhibit 3-5 are in 1993 dollars. The figures suggest that salt water fishing days are the highest valued type of activity day, followed thereafter by anadromous, cold-water, and warm-water fishing days. In all four categories of fishing activity, the estimates exhibit broad ranges: salt water fishing ($23.08-$271.27), anadromous fishing ($20.81-$157.17), cold-water fishing ($12.44-$145.88), and warm-water fishing ($10.04-$73.38).

The descriptive statistics presented in Exhibit 3-5 reveal the extent of possible fishing day values and intimate the difficulty of deriving a specification of fishing day values that is appropriate for the sample and geographic scale of the economic model. Since Vaughan and Russell modeled the benefits of water pollution control, much time and effort has been devoted to the analysis of recreational values. With the advent of benefits transfer and comparison of valuations research, there may be room for additional refinements of the approach discussed below and adopted by the economic model. Natural limitations to the refinement process are defined by the scale of existing data and modelling sources. Data such as the National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey is often organized at the state or national level, and the modelling precision of national waters is often limited to some state or regional level. These aggregate levels do not necessarily coincide with the appropriate scale for discussing recreational fishing opportunities and/or values. The range of fishing-day value estimates across methods, geographical areas, and fish species is made even clearer in Exhibit G-1 in Appendix G which summarizes the results from a select group of recreational valuation studies.

Exhibit 3-5
Net Economic Values per Recreation Day
Reported by TCM and CVM Demand Studies from 1968 to 1988
(1993 Dollars)[1]

Activity	Number of Estimates	Mean	Median	Standard Error of Mean	95% CI	Range
Cold-water fishing	39	37.82	35.19	4.94	29.97-45.66	12.44-145.88
Anadromous fishing	9	66.07	57.11	16.79	40.05-93.35	20.81-157.17
Warm-water fishing	23	29.08	27.79	3.75	23.13-35.65	10.04-73.38
Saltwater fishing	17	89.53	65.89	21.43	55.51-123.54	23.08-271.27

Source: Walsh et al., (1992).
[1] Values have been converted to 1993 dollars using the Consumer Price Index.

Because the economic model follows Vaughan and Russell (1982) quite closely, it is valuable to first describe what estimates these authors adopted for the average values of fishing days. Vaughan and Russell independently derived estimates from a two-stage travel cost method for trout and catfish fishing day values. They then calculated a value for a bass fishing day using information from Charbonneau and Hay (1978) about the differences in willingness to pay for catfish and trout days ($6) and bass and trout days ($2). The values for trout ($11), bass ($10), and catfish ($7) fishing days were used to represent the value of cold-water, warm-water, and rough fishing days respectively.

The economic model employs an approach quite close in spirit to this technique. The determination of the primary set of fishing day values involves combining two sources of information. First, the mean values of cold-water, anadromous, and warm-water fishing days reported in Walsh et al., 1992, were selected to serve as the basis for the values (see Exhibit 3-5. These values were derived from 71 empirical studies conducted between 1968 and 1988, and the value estimates from these studies were adjusted by the authors to establish some level of consistency across research methods. Adjusted to 1993 dollars using the Consumer Price Index, the mean fishing day values are $37.82 for cold-water fishing, $66.70 for anadromous fishing, and $29.08 for warm-water fishing. Because the thermal model includes anadromous fish species in its cold-water guild specification, a weighted average of these two mean values is used to reflect the value of a cold-water fishing day in the economic model. The weights were based on the number of cold-water and anadromous fishing days reported in the 1991 U.S. Department of Interior Fish and Wildlife Service National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (U.S. DOI, 1993). This first step established the fishing day values for cold-water and warm-water fishing days.

Next, it was necessary to take the mean values and combine them with another source of information to glean the relevant set of cold-water, cool-water, warm-water, and rough fishing day values. Similar to Vaughan and Russell (1982), the economic model relies on research completed by Charbonneau and Hay (1978). However, instead of using the differences in levels of willingness to pay, the economic model utilizes the relative sizes of the reported willingness to pay values for rough and warm-water fishing (0.79) as well as rough and cold-water fishing (0.60). Catfish values are used to represent rough fishing; bass values are used to represent warm-water fishing; and a weighted average between trout and salmon values are used to represent cold-water fishing. It is important to note that ideally all of the unit values would come from one source, but as will become apparent in the subsequent discussion of empirical works, few studies attempt to capture values for more than one type of fishing activity or more than one state. The Charbonneau and Hay (1978) study is a rare exception. This study was conducted in 1975 and employed travel cost and contingent valuation methods to derive nationally based fishing-day values for a variety of freshwater and saltwater fishing activities.

Three specifications of fishing-day values were adopted to assess the sensitivity of the model to the relative sizes of these values. Exhibit 3-6 presents the three specifications of fishing-day values. The primary specification of fishing-day values takes the modified Walsh et al., (1992) mean values for cold-water and warm-water fishing-day values; cool-water fishing days are assumed to be valued in the same way that cold-water fishing-day values are. Finally, the rough fishing-day value represents the product of the warm-water fishing-day value with the ratio of rough to warm value estimated by Charbonneau and Hay (1978). The high and low specifications of fishing-day values are alterations of the primary specification. In this context, high refers to widening the range of fishing-day values; while low suggests a narrowing of the range of values.[8]

The implementation of the economic model concludes with the derivation of twelve basic outputs for each climate scenario. These outputs include the changes in acreage by thermal

[8]No distinction is made in this study between net willingness-to-pay (WTP) for stream- and for lake-fishing. The measurement error involved is unknown. Even the direction of bias is unknown but it is speculated that stream cold-water fishing has higher net WTP. If so, the damages from lost stream cold-water fishing could be underestimated. In part, this possibility is captured by the high specification described here even though that did not explicitly motivate the specification.

category, the changes in fishing days by thermal category, and the associated changes in value (benefits or damages) by thermal category. The results section of this chapter is devoted to the comparison and contrast of these outputs for the different climate scenarios. Sensitivity analyses are also presented that reveal the importance of various assumptions and specifications employed by the thermal and economic models.

Exhibit 3-6
Fishing-Day Value Specifications
1993 Dollars

Fishing Activity	Primary	High	Low
Cold-water	41.75	45.93	41.75
Cool-water	41.75	41.75	29.08
Warm-water	29.08	29.08	29.08
Rough	22.96	20.66	24.96

3.5 ANNUAL ECONOMIC WELFARE EFFECTS, SELECTED YEARS AND MODELS

The entire framework for the thermal and economic modelling is constructed to estimate economic welfare effects for a single year in the future. Which year becomes the target is in part a function of the GCM used to drive the thermal modelling. The equilibrium GCMs (GFDL, GISS, OSU, UKMO) are anchored on the year or years during which an equilibrium state associated with the doubling of CO_2 is reached. Under the IPCC's central emission scenario (IS92a), radiative forcing equivalent to that associated with CO_2 doubling is expected sometime between 2060 and 2070 (IPCC, 1992, Figure Ax.3, p. 174). Different emissions assumptions could move the date forward or later. For the purposes of this analysis, the year 2060 is taken as the initial date.

For the transient GCMs, it is possible in theory to estimate the thermal profiles for different years. Exploiting this capability to an extreme would generate an enormous amount of data to manage, especially if, as is done in this study, regional- and month-specific data are needed. Consequently, only two time periods are characterized using the estimates from the transient GCM selected for this study. Those time periods are linked to two years commonly studied in climate analyses, 2050 and 2100. The results from these two specifications are labeled "TR 2050" and "TR 2100," where the TR designates the GFDL transient model.

These six models (GFDL, GISS, OSU, UKMO, TR 2050, TR 2100) constitute the main set of GCM results applied in the thermal-economic modelling. No attempt has been made to select one model as the best representative. Instead, estimates of economic impacts are provided for all six. The four equilibrium models, though normalized to a uniform, annual global climate sensitivity of 2.5°C, lead to different economic impacts because of spatial and temporal differences in the distribution of their thermal effects. Consequently, it is important to present all their results here. Including the transient model results corrects a shortcoming in the equilibrium GCMs. Because the latter are pegged to a very special and possibly fleeting circumstance (CO_2 doubling), they shed no light on the rate of climate change and present a significant analytical gap if the realized temperature increase in 2100 is very different from that in 2050. Unfortunately, the transient model is also not sufficient by itself, given the lack of consensus in GCM modelling.

This section presents the estimated annual economic welfare effects of climate change on recreational fishing for these selected GCMs and their associated time periods. Because the results could not all be adjusted to a common year, they are best viewed as a means for illustrating how the output of the thermal model (acreages by fish type) translates into different estimates of welfare effects. The next section will convert these results into comparable terms, estimating the present discounted value of the impacts in the model year and in subsequent years.

Exhibit 3-7 presents the estimated annual welfare impacts for the four equilibrium GCMs. For each fish type, both the thermal results, in terms of changes in "best-use" acreage, and the economic results are provided for each fish type (cold, cool, warm, rough). Damages occur when there is a loss in the value of a particular fishing type between the baseline and the time after climate change has occurred. These are depicted in parentheses, indicating negative values. For example, a loss of 2.5 million cold-water acres under the GFDL model is estimated to cause \$2.2 billion in cold-water fishing losses. The opposite case results in benefits. For example, a gain of 850 thousand cool-water acres leads to estimated benefits of \$305 million under the GFDL.

The net damages or benefits estimated for a particular model are the sum of the damages or benefits to cold, cool, warm, and rough fishing. For the primary specification of recreational fishing-day values, net benefits are estimated for two of the models (\$81 and \$80 million for the GFDL and GISS respectively) and net damages for the other two equilibrium models (-\$95 and -\$85 million for the OSU and UKMO respectively). Although there are losses in cold-water acreage estimated by all four models, these losses are offset by gains in cool, warm, and rough acres. Whether the loss of a cold-water acre is offset by a cool-water of other type of acreage is critical because of the equivalence assumed for the values of cold-water and cool-water fishing days in the primary specification. The two GCMs which produce net benefits under the primary specification (GFDL and GISS) have the largest increases in cool-water acreage. As a result, larger increases in the number of cool-water fishing days and smaller increases in the lower-valued warm-water fishing days are estimated in the economic model. Exhibit 3-8 illustrates these differences in estimated fishing days across the four models. The GFDL and GISS models are distinguished by their larger increases in cool-water fishing days. These circumstances provide a telling example of the importance of the specified fishing day values. If cool-water and warm-water fishing day values were combined, as Vaughan and Russell did, the gains in cool-water fishing days estimated for the GFDL, GISS, and, to a lesser extent, the UKMO would be worth a lot less. In contrast, the loss in cool-water fishing days calculated for the OSU model would have led to smaller economic damages, if cool- and warm-water fishing days were equally valued. Under this assumption, the net welfare effects for three of the models change signs. Losses are estimated for the GFDL and GISS models (-\$11 and -\$64 million respectively) and a gain is estimated for the OSU model (\$14 million). The damages associated with the UKMO model increase slightly, to -\$103 million. These results are shown in Exhibit 3-9.

The two transient specifications, for the years 2050 and 2100, provide further insight into the sensitivity of the estimated welfare effects to substitutions among the four fishing types. As Exhibit 3-10 shows, the largest damages observed for all six GCMs (-\$320 million) are estimated for the TR 2050 model. This phenomenon is influenced less by the loss of cold-water acreage (which contrary to what one might expect, is the smallest estimated for the six GCM models) than by the loss of cool-water acreage. This conclusion is reinforced by the results for the TR 2100 model, where the cold-water acreage losses are twice as large but are offset by gains in cool, warm, and rough acres. As a result, although this model represents the year 2100, when the average annual temperatures are estimated to be 1.25° C higher than in 2050 (2.75°C vs. 1.5° C), the economic damages are smaller though still substantial (-\$266 million per year). This trend is reversed when the values of cool- and warm-water fishing days are equated. Exhibit 3-11 shows that the net damages in the TR 2050 model (-\$76 million) are one-fourth the damages observed in the primary specification. Now, however, damages increase over time. The net damages estimated for the TR 2100 model increase slightly, to -\$286 million per year.

Exhibit 3-12 illustrates again how important the relative fishing day values are. For the TR 2050 model, the number of cold- and cool-water fishing days lost (50 million) are more than offset by the number of warm-water and rough fishing days gained (64 million) but there is an overall net economic loss because cold- and cool-water days have been assigned a higher value. For the TR 2100 model, the number of days gained on net is even greater (24 million) but again, welfare losses rather than gains are still estimated. These results illustrate another feature of the economic model. The redistribution of freshwater acreage to warm-water "best uses" leads to an overall increase in the number of fishing days estimated for U.S. anglers. This tendency in the economic model underscores the importance of how trade-offs in the different acreage types are modelled. As the economic model is currently implemented, the loss in cold-water acreage translates directly into an expansion of cool, warm, and rough fishing opportunities. This assumption will be investigated further in the sensitivity analyses.

Exhibit 3-7
Estimated Annual Economic Welfare Effects
Primary Specification

(Damages) and Benefits in Millions of Dollars

Model	Fish Type									
	Cold		Cool		Warm		Rough		None	Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits
GFDL	(2,537,112)	($2,166)	849,823	$305	1,305,773	$1,381	366,201	$561	15,315	$81
GISS	(1,965,543)	($1,724)	745,538	$472	875,839	$903	337,605	$428	6,561	$80
OSU	(2,275,028)	($1,904)	476,188	($358)	1,474,973	$1,668	308,552	$499	15,315	($95)
UKMO	(3,037,818)	($2,473)	697,951	$60	1,526,839	$1,726	746,236	$603	66,793	($85)

Note: All Models are 2 x CO_2 equilibrium models which have been normalized to a global climate sensitivity of 2.5 degrees Celsius.

Exhibit 3-8

Changes in Fishing Days By Type Different Equilibrium GCMs

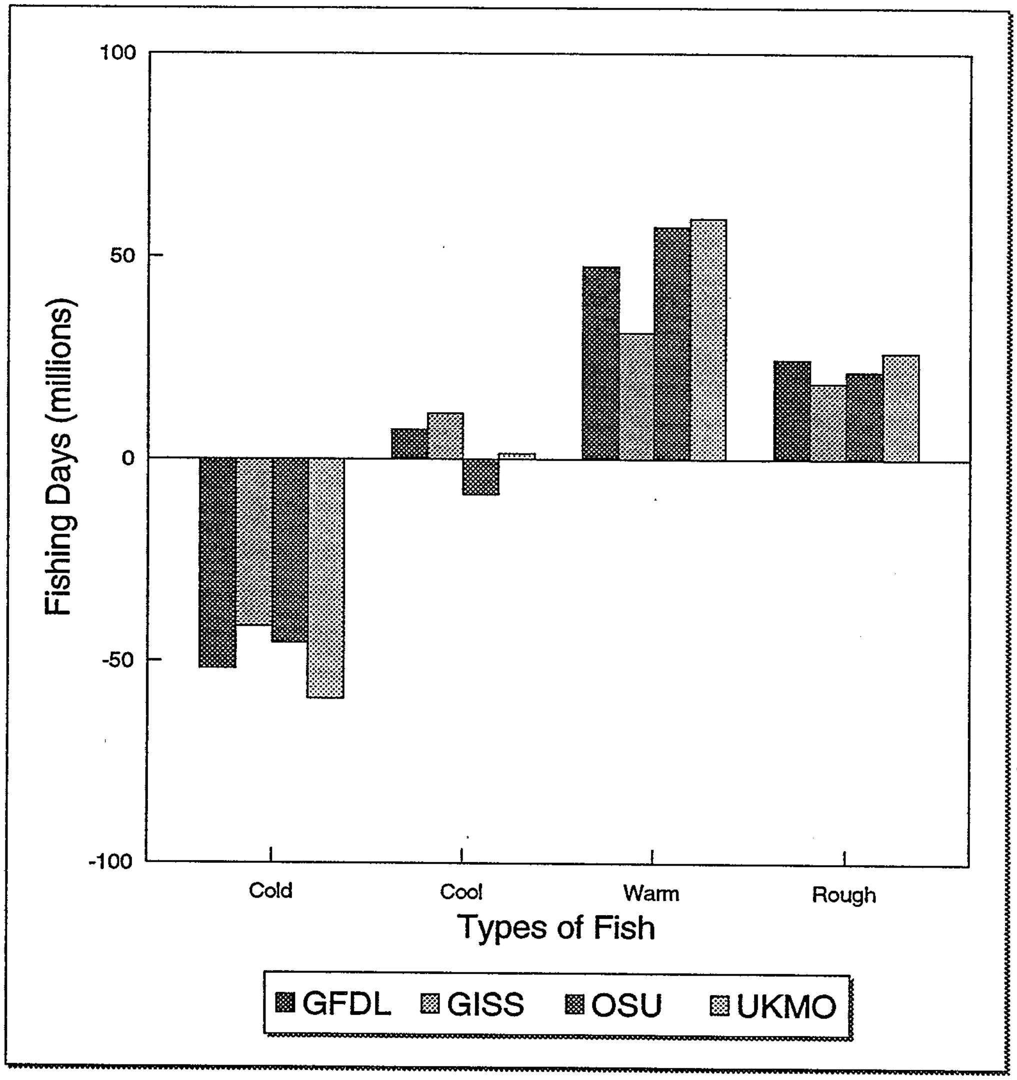


Exhibit 3-9
Estimated Annual Economic Welfare Effects
Specification Equates Cool- and Warm-water Fishing Day Values[1]

(Damages) and Benefits in Millions of Dollars

Model	Fish Type									
	Cold		Cool		Warm		Rough		None	Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits
GFDL	(2,537,112)	($2,166)	849,823	$213	1,305,773	$1,381	366,201	$561	15,315	($11)
GISS	(1,965,543)	($1,724)	745,538	$329	875,839	$903	337,605	$428	6,561	($64)
OSU	(2,275,028)	($1,904)	476,188	($249)	1,474,973	$1,668	308,552	$499	15,315	$14
UKMO	(3,037,818)	($2,473)	697,951	$42	1,526,839	$1,726	746,236	$603	66,793	($103)

[1]The fishing-day values used in this specification were $41.75 (cold), $29.08 (cool and warm), and $22.96 (rough). All Models are 2 x CO_2 equilibrium models which have been normalized to a global climate sensitivity of 2.5 degrees Celsius.

Exhibit 3-10
Estimated Annual Economic Welfare Effects
Primary Specification

(Damages) and Benefits in Millions of Dollars

Model	Fish Type									
	Cold		Cool		Warm		Rough		None	Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits
GFDL TR 2050	(1,409,421)	($1,290)	(90,838)	($805)	1,132,970	$1,467	360,728	$308	6,561	($320)
GFDL TR 2100	(3,321,153)	($2,741)	841,548	$66	1,654,019	$1,792	810,271	$617	15,315	($266)

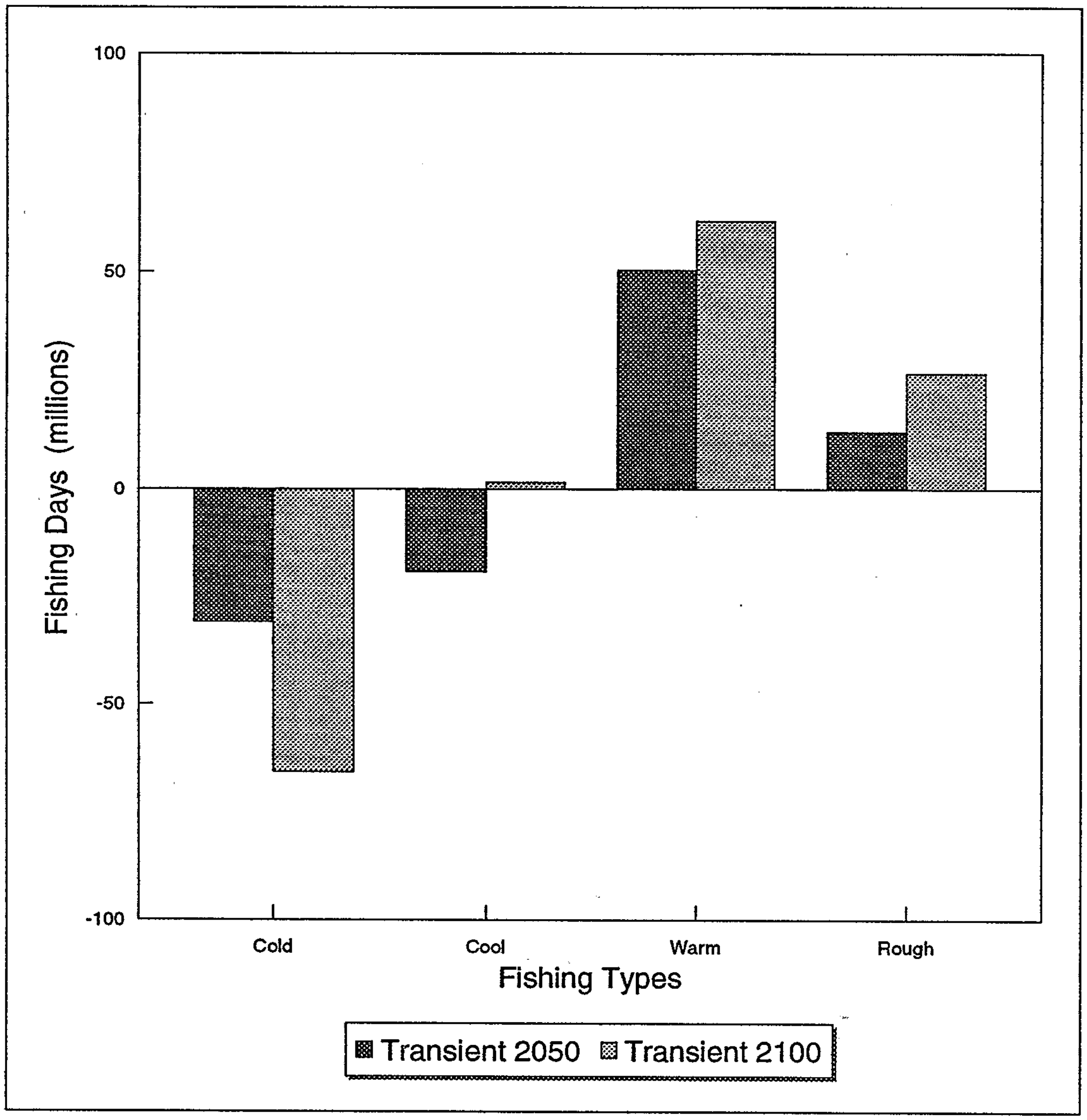
Exhibit 3-11
Estimated Annual Economic Welfare Effects
Specification Equates Cool- and Warm-Water Fishing Day Values

(Damages) and Benefits in Millions of Dollars

Model	Fish Type									
	Cold		Cool		Warm		Rough		None	Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits
GFDL TR 2050	(1,409,421)	($1,290)	(90,838)	($561)	1,132,970	$1,467	360,728	$308	6,561	($76)
GFDL TR 2100	(3,321,153)	($2,741)	841,548	$46	1,654,019	$1,792	810,271	$617	15,315	($286)

Exhibit 3-12

Changes in Fishing Days By Type
Different Transient Benchmarks



3.6 PRESENT DISCOUNTED ECONOMIC WELFARE EFFECTS

The current analysis is confined to estimating climate change effects for selected years (2050, 2060, and 2100). To encompass the long time-frame considered relevant for these effects, it is necessary to extrapolate the results from the selected years to other years in the future. The results of the previous section provided ambiguous guidance on how any extrapolation should be made. Even though the temperature increases associated with climate change are expected to grow continuously from the present until at least the year 2100, the estimated damages for the transient GCM rose from 2050 to 2100 under one specification of the fishing day values and fell under another. Consequently, it is difficult to identify the possible bias of even the simplest extrapolation, such as holding the welfare effects constant into the future. This approach does, however, have the advantage of reducing the expected bias if upward and downward tendencies in the damage estimates are equally likely. On this basis, holding the estimated damages constant was chosen as the procedure for extrapolating from the selected years to subsequent years.

Greater care appears to be warranted for the years prior to the selected study years. Although the estimated annual damages associated with them are likely to be smaller than those estimated for 2050 and 2060, they are discounted less and therefore carry greater weight in the present value of welfare effects calculated for 1994. For the current study, a conservative approach was taken. In the absence of more specific evaluation, zero effects were assumed for the time period between the present and the years 2050 and 2060, the relevant start years for the transient and equilibrium scenarios, respectively. This assumption has not yet been considered in a sensitivity analysis but it should be eventually.

Exhibits 3-13 and 3-14 summarize in graphical terms the assumptions applied to the estimated annual effects. Though couched in terms of damages, they apply analogously to those cases where net benefits have been estimated. The approach taken to the equilibrium results is straightforward. The estimated effects are applied to the approximate year when CO_2 doubling is expected and to all subsequent years until 2193, approximately two hundred years from the present. Damages in the years after 2100 can have either a little or a tremendous influence on the present discounted welfare effect, depending on whether a low (1%) or a high (7%) discount rate is applied.

The approach taken to the transient results departs slightly from the equilibrium approach. Damages start sooner (2050), are based on the 2050 transient model, are held constant until 2100, and change then to the damages estimated for 2100 in the transient model. The damages are held constant at this level from 2100 to 2193.

Extremely long time-frames magnify the difficulty in selecting an appropriate discount rate. Present values can differ by two orders of magnitude when rates of 1 percent and 7 percent are applied to this study's results. Evidence reviewed by Freeman suggests that the after-tax real rate of interest, a basis for estimating individuals' rates of time preference, falls in the range of 1 percent to 4 percent (Freeman, 1993a), which lowers the difference to an order of magnitude. Scheraga points to historical experience with real after-tax returns on Treasury bills and stocks as justification for using 3 percent as a consumption rate of interest (Scheraga, 1989). Several critiques of discounting, including ones from economists, have suggested that discounting is not suitable for circumstances where multiple generations are involved. Freeman, for example, argues that the trade-off across time that is implicit in the derivation of rates of time preference are not feasible for multiple generations. Taken together, those views support using an even lower discount rate. The discussion presented below focuses on the results for a 1 percent discount rate. For completeness, results based on rates from 2 percent to 7 percent are also provided.

Present discounted welfare effects for the six models, based on the primary specification of fishing day values, are presented in Exhibit 3-15. As was observed in the previous section, the equilibrium results are mixed for this specification. Two equilibrium models exhibit benefits and the other two, damages. For a 1 percent discount rate, the present values range from $4 billion in damages to $3 billion in benefits.

The maximum damages do not change substantially when equal values for cool- and warm-water fishing days are used, as shown in Exhibit 3-16 but signs of the other three models' results change. As a result, under this specification, three models have estimated damages ranging from $424 million to $4.0 billion and one model (OSU) has estimated benefits of $540 million.

Exhibits 3-15 and 3-16 also present the estimated present value of damages for the transient model. While this model is also affected by alternate assumptions regarding the value of various types of fishing days, the results for the two specifications are more robust than they were for the equilibrium models. Damages of -$12.9 billion and -$7.8 billion are estimated for the primary and alternate specifications of relative fishing day values. These estimated damages are two to three times larger than any estimated damages based upon the equilibrium models.

Exhibit 3-13

Present Discounted Value: Equilibrium GCM
Assumed Distribution of Damages

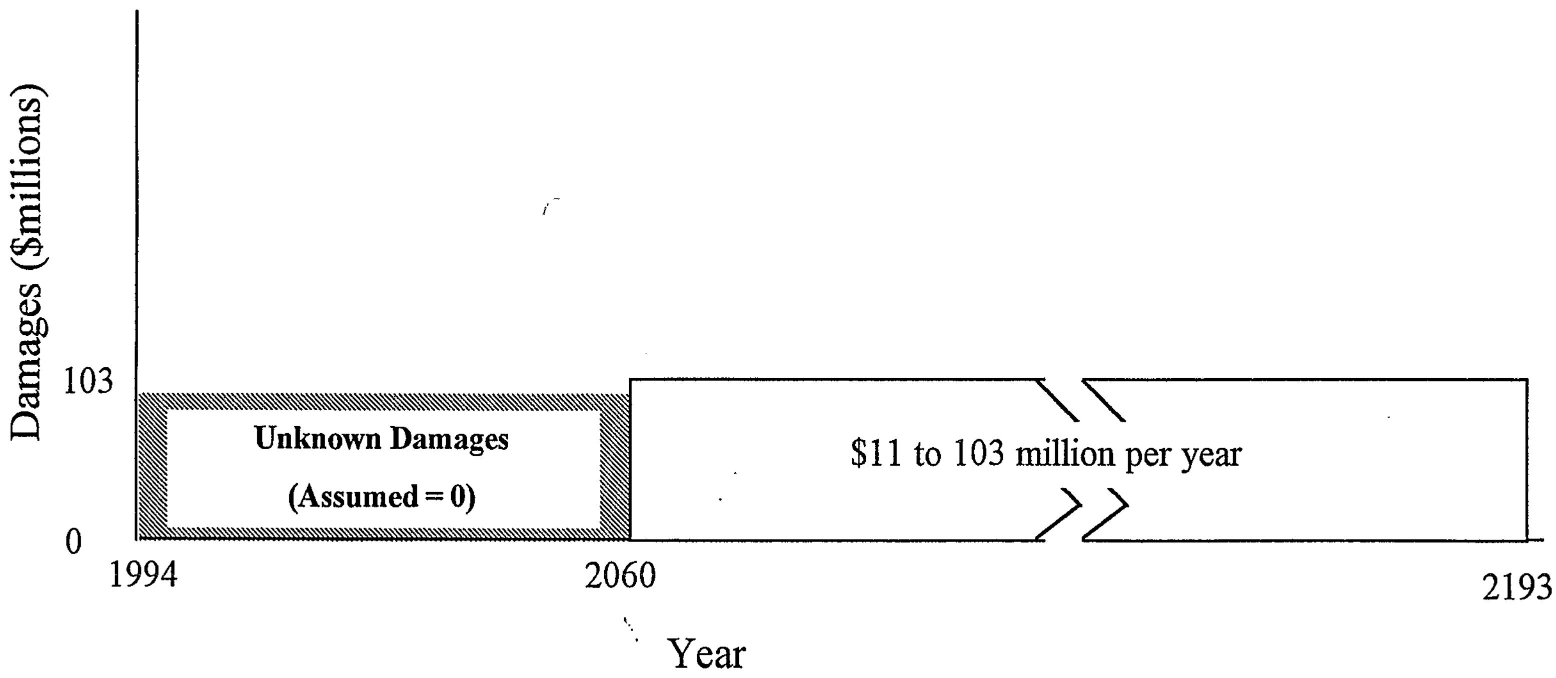


Exhibit 3-14

Present Discounted Value: Transient GCM Assumed Distribution of Damages

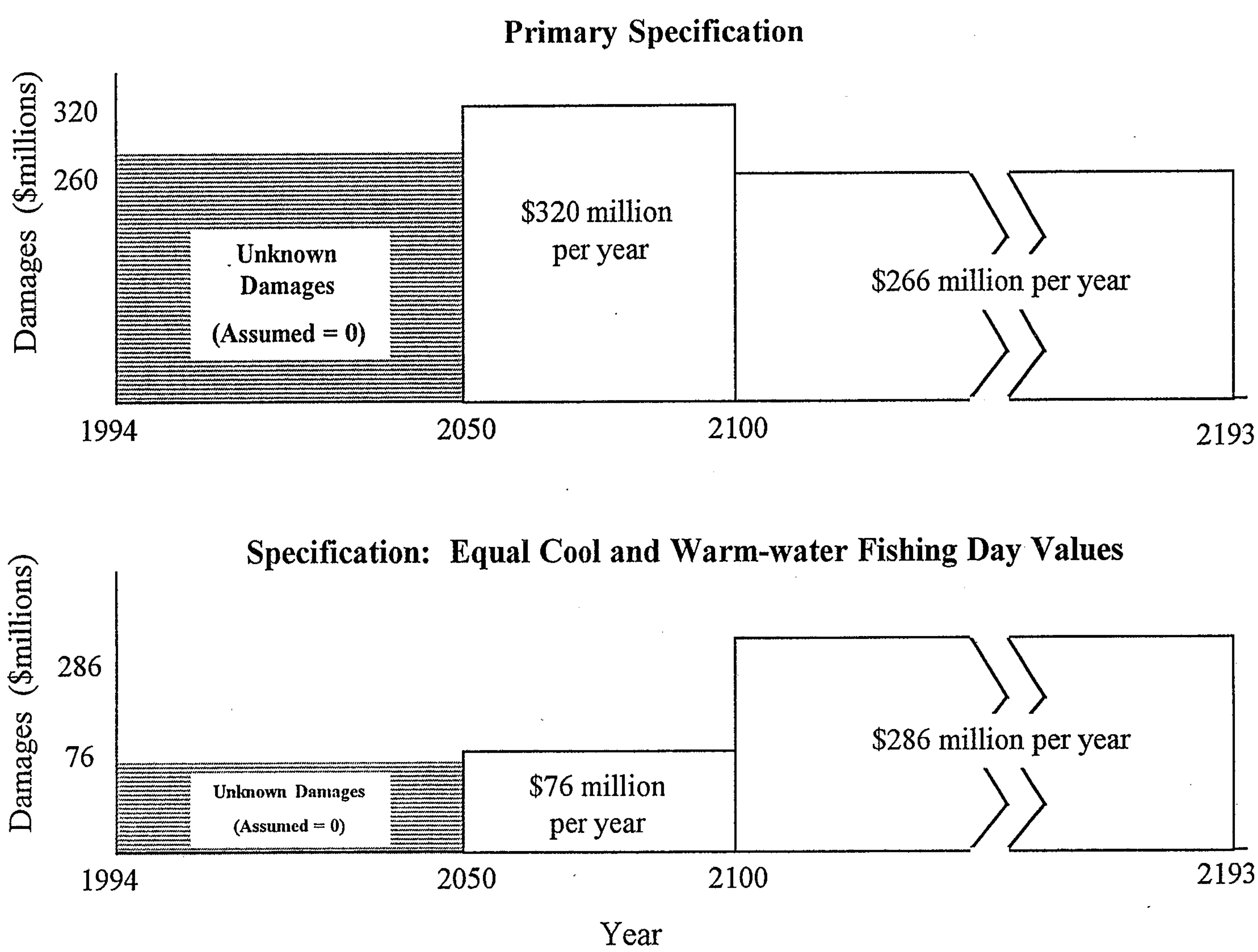


Exhibit 3-15
Present Discounted Welfare Effects: Net (Damages) or Benefits
Primary Specification
(1993 $millions)

Scenario	Interest Rate						
	1%	2%	3%	4%	5%	6%	7%
GFDL, 2060-2193	3,124	1,039	388	157	68	31	14
GISS, 2060-2193	3,085	1,026	383	155	67	30	14
OSU, 2060-2193	(3,664)	(1,219)	(455)	(185)	(80)	(36)	(17)
UKMO, 2060-2193	(3,278)	(1,091)	(407)	(165)	(71)	(32)	(15)
Transient, 2050-2193	(12,941)	(4,788)	(1,993)	(901)	(431)	(214)	(110)

Exhibit 3-16
Present Discounted Welfare Effects: Net (Damages) or Benefits
Specification: Equal Values of Cool- and Warm-water Fishing Days
(1993 $millions)

Scenario	Interest Rate						
	1%	2%	3%	4%	5%	6%	7%
GFDL, 2060-2193	(424)	(141)	(53)	(21)	(9)	(4)	(2)
GISS, 2060-2193	(2,468)	(821)	(306)	(124)	(54)	(24)	(11)
OSU, 2060-2193	540	180	67	27	12	5	2
UKMO, 2060-2193	(3,973)	(1,322)	(493)	(200)	(86)	(39)	(18)
Transient, 2050-2193	(7,836)	(2,314)	(786)	(302)	(129)	(59)	(29)

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4. EVALUATION OF THE ANALYTICAL FRAMEWORK

4.1 INTRODUCTION

The results and methodology discussed in Chapters 2 and 3 are those employed for the primary specification of ecologic and economic input variables and modelling assumptions. Chapter 4 presents several different analyses that incorporate alternative specifications for these input variables and modelling assumptions. In keeping with the objective of this study to identify potential damages while attempting to minimize any biases that might overstate or understate the estimated damages, the primary specification was constructed using conservative assumptions. It is important to note, however, that several of the alternative specifications may be equally valid as the primary specification as the appropriate basis for analysis. The current state of knowledge about recreational fishing behavior does not allow a definitive choice among alternative specifications. In this sense, the primary specification may be a reasonable choice but is still highly debatable. What typically distinguishes the primary specification from the alternatives is that the latter tend to result in much higher or small estimated damaged. The value of conducting sensitivity analysis is manifested in the following sections, as the importance of certain variables and modelling assumptions are made clear. These types of discoveries provide a better understanding of the context in which to view the primary specification results and often point to areas for further research.

Sections 2 through 8 of Chapter 4 summarize seven evaluations of the models that were conducted as part of the modelling of ecological impacts from global climate change. The sections address revisions to ecologic as well as economic modelling components. The seven analyses include modifications of the treatment of or assumptions associated with (1) fishing-day values; (2) climate and emission scenarios sensitivity; (3) fish thermal tolerances; (4) fish habitats; (5) warm-water fishing behavior; (6) cold-water acreage substitutability; and (7) runoff. The discussions in each of the sections emphasize the extent to which the results change relative to the primary specification. This provides some indication of the 'importance' of the assumptions. Additional attention is devoted to the changes in acreage and valuation patterns within and across global climate change scenarios.

4.2 FISHING-DAY VALUES

As discussed in Chapter 3, the economic model is run using three different recreational fishing-day value specifications. These specifications are referred to as low, primary, and high. The specifications employ the following sets of values for cold-, cool-, warm-water, and rough fishing-day values: low ($41.75, $29.08, $29.08, and $24.96); primary ($41.75, $41.75, $29.08, and $22.96); and high ($45.93, $41.75, $29.08, and $20.66). The sets of values differ according to their specification of the relative worth of types of recreational fishing activities.

The variations are primarily associated with the handling of cool-water fishing days and rough fishing days.

As discussed earlier, the primary specification of fishing-day values is based on the Walsh et al. (1992) values for cold-water and warm-water fishing days. The primary specification rates cold-water fishing days and cool-water fishing days equivalently and assigns the rough fishing-day value as the product of the warm-water fishing-day value with the rough to warm-water fishing-day value ratio derived from Charbonneau and Hay(1978) estimates. In contrast, the low specification of recreational fishing-day values assigns equal values to warm-water and cool-water fishing days and derives the rough fishing-day value using the Charbonneau and Hay (1978) rough to cold-water fishing-day value ratio. Relative to the primary specification, the low specification awards less value to the loss in cool-water fishing days and more value to the increase in rough fishing days. The high specification of recreational fishing-day values is defined by extending the range of fishing-day values. To form the high specification, the primary cold-water fishing-day value is increased by 10 percent and the primary rough fishing-day value is lessened by 10 percent. These adaptations cause the high specification to allocate more weight to the loss in cold-water fishing days and less value to the increase in rough fishing-day values relative to the primary specification.

The economic model produces estimates of the changes in acres and fishing days by best-use activity and calculates the associated value (benefits or damages) of these transitions. Central to this calculation are the tradeoffs between the different types of recreational fishing activities. In short, the economic model characterizes the welfare implications of shifts in recreational fishing opportunities. In the context of global climate change, these shifts involve movements from cool-water fishing activities to warm-water fishing activities. By design, the final results (benefits or damages) are quite sensitive to the relative magnitudes of the values across fishing activities.

Exhibit 4-1 displays the output of the economic model for four equilibrium scenarios (GF1, GI1, OS1, and UK1) and two transient scenarios (TR1 and TR2). For each scenario, the estimated changes in fishing days and changes in value are presented under the low, primary, and high fishing-day value specifications. To emphasize the differences across specifications, total and activity-specific (i.e., cold, cool, warm, and rough) changes are presented. Comparing the low, primary, and high results, several interesting patterns appear. In the UK1, TR1, and TR2 scenarios, the size of the estimated damages from climate change increase successively moving from the low to primary to high specifications. This same trend holds for the OS1 scenario, but interestingly enough, there is a sign change moving from the low specification(benefits of 57 million dollars) to the primary specification(damages of 95 million dollars). The GI1 scenario stands out from the other scenarios as the low and high specifications predict damages of approximately 26 and 136 million dollars and the primary specification estimates benefits of approximately 80 million dollars.

Exhibit 4-1
Assessing Sensitivity to Fishing-Day Values

Scenario	Changes in Fishing Days (1,000s)	Changes in Dollar Value, Low[1] (Millions)	Changes in Dollar Value, Primary[2] (Millions)	Changes in Dollar Value, High[3] (Millions)
GF1	**27,367**	**38**	**81**	**(191)**
Cold	(51,876)	(2,166)	(2,166)	(2,383)
Cool	7,307	213	305	305
Warm	47,488	1,381	1,381	1,381
Rough	24,448	610	561	505
GI1	**19,733**	**(26)**	**80**	**(136)**
Cold	(41,292)	(1,724)	(1,724)	(1,897)
Cool	11,301	329	472	472
Warm	31,064	903	903	903
Rough	18,660	466	428	386
OS1	**24,918**	**57**	**(95)**	**(335)**
Cold	(45,593)	(1,904)	(1,904)	(2,094)
Cool	(8,572)	(249)	(358)	(358)
Warm	57,337	1,668	1,668	1,668
Rough	21,746	543	499	449
UK1	**27,793**	**(50)**	**(85)**	**(393)**
Cold	(59,230)	(2,473)	(2,473)	(2,720)
Cool	1,428	42	60	60
Warm	59,338	1,726	1,726	1,726
Rough	25,257	655	603	542

Scenario	Changes in Fishing Days (1,000s)	Changes in Dollar Value, Low[1] (Millions)	Changes in Dollar Value, Primary[2] (Millions)	Changes in Dollar Value, High[3] (Millions)
TR1	**13,690**	**(49)**	**(320)**	**(480)**
Cold	(30,906)	(1,290)	(1,290)	(1,420)
Cool	(19,272)	(561)	(805)	(805)
Warm	50,441	1,467	1,467	1,467
Rough	13,427	335	308	277
TR2	**24,439**	**(232)**	**(266)**	**(602)**
Cold	(65,652)	(2,741)	(2,741)	(3,015)
Cool	1,576	46	66	66
Warm	61,621	1,792	1,792	1,792
Rough	26,894	671	617	556

Notes:
The specifications for fishing-day values include values for cold, cool, warm, and rough water fishing days.
[1] The low specification is 41.7548; 29.0843; 29.0843; and 24.9610.
[2] The primary specification is 41.7548; 41.7548; 29.0843; and 22.9562.
[3] The high specification is 45.9303; 41.7548; 29.0843; and 20.6606.

4.3 CLIMATE AND EMISSIONS SCENARIO SENSITIVITY

The thermal model simulates changes in fish presence as a function of increasing temperatures using estimates produced from different general circulation models(GFDL, GISS, OSU, and UKMO) and emissions scenarios. The general circulation models and emission scenarios work in tandem, with the general circulation model predicting changes in the level of warming for the concentration of the gases in the atmosphere designated by the emission scenarios. The emission scenarios data reflect projected estimates of various greenhouse gas emissions which in turn are based on various assumptions concerning population growth, energy use, industrial technologies, economic circumstances, and tropical deforestation and forest biomass. Because of the complexity of projecting emissions over time, there is considerable uncertainty associated with the projected emissions scenarios. The primary specification discussed in Chapter 2 focuses on the best or median emission estimates (IS92a). In this sensitivity analysis, the results for the primary (1), low (2), and high (3) emission scenarios are presented for four equilibrium scenarios (GFDL; GISS; OSU; and UKMO) and two transient scenarios (TR1 and TR2). These three specifications represent different levels of climate sensitivity to greenhouse gas emissions. The high and low specifications respectively result in greater and lesser global mean temperature increments than the primary specification.

The climate sensitivity assumptions affect the output of the economic model by modifying the way in which best-use fishing acreage is shifted from one thermal category to another. These shifts in acreage change the predicted estimates of general fishing participation, fishing participation by type of activity, and the number of days devoted to the different fishing activities. In general, it is expected that higher (lower) temperature increments will result in greater (smaller) decreases in the higher valued cold-water and cool-water fishing days and greater (smaller) increases in the lesser valued warm-water and rough fishing days relative to the primary increment. The relative sizes of these counteracting changes in value determine the estimated sign of the dollar value associated with the predicted recreational fishing behavior response. The equilibrium and transient models are discussed separately, for the models employ different sets of temperature increments.

4.3.1 Equilibrium models

The climate sensitivity assumptions adopted for the twelve equilibrium models are based on three levels of projected increases in temperature: 1.5° C, 2.5° C, and 4.5° C (refer to Exhibit 4-2). These three increments correspond to the low (2), primary (1), and high (3) climate sensitivity specifications. Exhibit 4-2 presents the results from the twelve equilibrium scenarios. The results are organized by general circulation model. The numbering reflects the different assumptions concerning temperature increments. The lower temperature increment applies to models GF2, GI2, OS2, and UK2. The higher temperature increase is used for GF3, GI3, OS3, and UK3. The middle or median level temperature increase applies to GF1, GI1, OS1, and UK1. Exhibit 4-3 displays the estimated changes in acres and changes (benefits or damages) in dollar value associated with each scenario.

Best-use cold acreage falls relative to the primary specification for all of the high temperature increment scenarios. The UK3 scenario shows the highest loss (4.2 million) in best-use cold-water acreage, while the GI3 and OS3 scenarios reveal the lower decreases (3.6 million) in cold-water acreage. Best-use cool-water acreage decreases in all of the high and low specifications relative to the primary specification in all but one of the scenarios (OS2). The OS2 scenario shows higher levels of best-use cool-water acreage in the low specification relative to the primary specification. The increases in best-use warm-water and rough acres are greater (smaller) for the high (low) specifications than the primary specification.

Exhibit 4-2

Global Annual Mean Temperature Increases Used to Scale Equilibrium GCM Results

GCM Run	IPCC Climate Sensitivity[1]		
	Low	Primary	High
GFDL/ Equilibrium	1.5°C **GF2**	2.5°C **GF1**	4.5°C **GF3**
GISS/ Equilibrium	1.5°C **GI2**	2.5°C **GI1**	4.5°C **GI3**
OSU/ Equilibrium	1.5°C **OS2**	2.5°C **OS1**	4.5°C **OS3**
UKMO/ Equilibrium	1.5°C **UK2**	2.5°C **UK1**	4.5°C **UK3**

Notes:
[1] IPCC 1992. (p. 10.) All GCMs reflect equilibrium effects from the doubling of CO_2.

Several interesting patterns appear in the results of the sensitivity analyses presented in Exhibit 4-3. The models with high temperature increases return total damages in every scenario. The estimated damages under the high specification range from 131 million dollars in the GI3 scenario to 751 million dollars in the UK3 scenario. Conversely, the models with low temperature increases yield total benefits across all scenarios. The estimated benefits range from 36 million dollars in the GI2 scenario to 395 million dollars in the GF2 scenario. The dollar values associated with the primary specification models all fall between the two extremes except in the case of the GI1 scenario. The GI1 primary scenario has higher estimated benefits (80 million dollars) than the low temperature increment scenario GI2 (36 million dollars). This departure from the expected relationship (higher damages with higher temperatures) is attributed to the low ratio (1 to 8) of benefits from cool-water fishing for GI2 (56 million dollars) compared to GI1(472 million dollars). The relative sizes of the cold, warm, and rough benefits or damages of the GI2 and GI1 scenarios are 1 to 2, 2 to 3, and 1 to 2 respectively.

The greatest changes in dollar value relative to the primary climate sensitivity specification appear for the UK1 and GF1 high specification runs. In these runs, the estimated dollar values fall relative to the primary specification by 666 and 642 million dollars respectively. For the low climate sensitivity runs, the changes in dollar value relative to the

Exhibit 4-3
Alternate Climate Sensitivity Assumptions for Primary Fishing-day Values
Annual (Damages) and Benefits in Millions of Dollars

Model	Cold		Cool		Warm		Rough		None		Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
Equilibrium Models											
GF3 High	(3,928,058)	($3,301)	322,601	($1,203)	2,676,282	$3,153	892,927	$790	36,247	--	($561)
GF1 Primary	(2,537,112)	($2,166)	849,823	$305	1,305,773	$1,381	366,201	$561	15,315	--	$81
GF2 Low	(1,164,566)	($1,331)	538,223	$940	323,129	$410	296,102	$375	7,110	--	$395
GI3 High	(3,612,562)	($3,085)	594,757	($251)	2,039,308	$2,422	866,466	$781	112,032	--	($131)
GI1 Primary	(1,965,543)	($1,724)	745,538	$472	875,839	$903	337,605	$428	6,561	--	$80
GI2 Low	(644,477)	($866)	(27,365)	$56	384,454	$623	287,389	$223	0	--	$36
OS3 High	(3,623,815)	($3,080)	251,946	($1,201)	2,558,272	$3,054	735,263	$761	78,334	--	($467)
OS1 Primary	(2,275,028)	($1,904)	476,188	($358)	1,474,973	$1,668	308,552	$499	15,315	--	($95)
OS2 Low	(1,509,394)	($1,311)	802,019	$650	589,474	$508	111,340	$335	6,561	--	$183

Model	Cold		Cool		Warm		Rough		None		Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
UK3 High	(4,221,172)	($3,343)	(47,100)	($1,923)	3,050,688	$3,699	1,062,274	$816	155,309	--	($751)
UK1 Primary	(3,037,818)	($2,473)	697,951	$60	1,526,839	$1,726	746,236	$603	66,793	--	($85)
UK2 Low	(1,284,780)	($1,292)	223,838	$107	720,304	$947	334,077	$351	6,561	--	$113

primary specification range from a 44 million reduction in dollar value under the GI1 scenario to a 314 million increase in dollar value under the GF1 scenario relative to the primary climate sensitivity specification.

4.3.2 Transient models

The climate sensitivity assumptions adopted for the transient models rest on two sets of estimated temperature changes: 0.9°C, 1.5°C, and 2.4°C for TR3, TR1, and TR5; and 1.65°C, 2.75°C, and 4.4°C for TR4, TR2, and TR6 (refer to Exhibit 4-4). These temperature increments represent the low, primary, and high specifications. Exhibit 4-5 presents the results from the six transient model scenarios. The lower temperature increment applies to models TR3 and TR4. The higher temperature increase is used for TR5 and TR6. The middle or median level temperature increase applies to TR1 and TR2. Exhibit 4-5 displays the estimated changes in acres and changes(benefits or damages) in dollar value associated with each scenario.

The estimated changes in cold-water, warm-water, and unfishable acres are consistent with expectations. Higher increases in temperature reduce cold-water acres more and increase warm-water and unfishable acres more than lower temperature changes. Specifically, the high specifications (TR5 and TR6) exhibit larger cold-water acreage decreases and larger warm-water and unfishable average increases than their counterparts in the primary specifications (TR1 and TR2). Because of threshold effects in the conversion of cold-water acres to other categories, among other causes, changes in cool-water and rough acreage do not coincide with expectations based solely on the direction of temperature changes. Higher temperatures increases result in <u>fewer</u> cool-water and rough acres (TR2 vs. TR6) since warm-water and unfishable acres increase so dramatically.

The trends in estimated shifts in best-use acreage are reflected in the changes in dollar value associated with the recreational fishing behavior responses. The transient models with high temperature increases (TR5 and TR6) both yield total damages. The models with low temperature increases (TR3 and TR4) yield damages and benefits respectively. The TR4 scenario yields benefits of $256 million, which contrasts with the predicted damages of $266 million of the TR2 primary scenario. The TR3 low scenario results in damages ($70 million) smaller than those predicted by the primary TR1 scenario ($320 million). The expected relationship (higher temperatures, greater damages) between climate settings holds true for the TR6, TR2, and TR4 grouping but not for the TR1, TR3, and TR5 grouping. The damages estimated for the TR5 scenario ($265 million) are lower than the damages estimated for the TR1 scenario ($320 million) (Exhibit 4-5). The discrepancy is explained by the relative sizes of the damages from reductions in cold and cool best-use acreage and the benefits of increases in warm and rough best-use acreage.

The greatest change in dollar value relative to the primary specification results appears for the TR2 low climate sensitivity specification where the estimated dollar value increases relative to the primary climate sensitivity specification by $522 million. In the case of the high specification for the TR2 model, the change in dollar value falls by $296 million relative to the primary climate sensitivity result. The TR1 model shows increases in dollar value relative to the primary climate sensitivity run for both the high ($55 million) and low ($250 million) climate sensitivity specifications.

Exhibit 4-4
Global Annual Temperature Increases
Used to Scale Transient GCM Results

GCM Run	IPCC Climate Sensitivity[1]		
	Low	Primary	High
GFDL/ Transient "1.16°C decade"	0.9°C in 2050 **TR3**	1.5°C in 2050 **TR1**	2.4°C in 2050 **TR5**
GFDL/ Transient "Eighth decade"	1.65°C in 2100 **TR4**	2.75°C in 2100 **TR2**	4.4°C in 2100 **TR6**

Notes:
[1] The GCMs were normalized to each of the climate sensitivity assumptions using the rates of temperature increase observed in IPCC (1972) estimates as interpreted by EPA (Leary, 1994).

Exhibit 4-5
Alternate Climate Sensitivity Assumptions for Primary Fishing Day Values
(Damages) and Benefits in Millions of Dollars

Model	Cold		Cool		Warm		Rough		None		Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
Transient Models											
TR5 High	(3,350,741)	($2,726)	865,260	($27)	1,745,102	$1,865	733,268	$623	7,110	--	($265)
TR1 Primary	(1,409,421)	($1,290)	(90,838)	($805)	1,132,970	$1,467	360,728	$308	6,561	--	($320)
TR3 Low	(581,980)	($603)	51,013	$62	242,013	$349	288,954	$123	0	--	($70)
TR6 High	(3,785,070)	($3,182)	229,713	($1,375)	2,713,698	$3,214	771,926	$775	69,733	--	($567)
TR2 Primary	(3,321,153)	($2,741)	841,548	$66	1,654,019	$1,792	810,271	$617	15,315	--	($266)
TR4 Low	(1,418,542)	($1,526)	544,732	$862	430,599	$539	436,101	$381	7,110	--	$256

4.4 FISH THERMAL TOLERANCE DESIGNATIONS

The thermal tolerance assumptions determine the manner in which species and therefore guilds of fish change with the predicted thermal dynamics and shifts in best-use fishing acreage. There is considerable uncertainty associated with the specification of thermal tolerances as well as with the methodology for deriving guild information based on the well-being of selected species within a guild. The purpose of this sensitivity analysis is to examine the ways in which the tolerance assumptions affect the outputs of the economic model and to compare these effects across several different global climate models.

The model was run using three specifications of thermal tolerances. The results discussed in Chapters 2 and 3 focus on the primary specification. The high and low tolerance specifications are modifications of the primary specification, as the primary, high, and low tolerances are the Fish-Temperature Data Matching System 95th percentile (FTDMS) numbers, plus and minus their standard error. For a discussion of the FTDMS, please refer to Chapter 2. The sets of specifications were adopted for four equilibrium models (GF1, GI1, OS1, and UK1) and two transient models(TR1 and TR2).

The high and low tolerance assumptions should provide smaller and greater changes in damages respectively, relative to the primary tolerance specification. When thermal tolerances are raised, the number of fish in each guild that can survive or adapt to increased temperature dynamics rises. Within the structure of the thermal model, this increase results in fewer shifts in best-use fishing acreage. Benefits are generated when fewer high valued cold and cool-water acres (and fishing days) are lost because of the higher thermal tolerances. Lowering thermal tolerances decreases the number of fish in every guild that can survive or adapt to a temperature increase. In this situation, more damages are generated as more highly valued cold and cool-water acres (and fishing days) are shifted to a lesser valued best-use acreage designation.

4.4.1 Equilibrium Models

Exhibit 4-6 presents the results from the thermal tolerance sensitivity runs for the four equilibrium models (GF1, GI1, OS1, and UK1). Changes in acres and changes in the dollar value of fishing days are presented for the different thermal categories. The best-use cold acreage reductions parallel the thermal tolerance specifications (i.e., low tolerance, higher cold acreage loss) for all of the models except for UK1. The UK1 model has a higher loss of best-use cold acreage under the primary specification (3.0 million acres) than under the low specification (2.2 million acres). This same pattern of best-use acreage shifts holds for cool-water and warm-water acreage; while the shifts in best-use rough acreage under the different thermal tolerance specifications vary tremendously across the different models.

Changes in dollar value associated with the changes in recreational fishing behavior are consistent across all the equilibrium models. Moving from the high to low tolerance

Exhibit 4-6
High, Primary, and Low Thermal Tolerance Results for Primary Fishing-Day Values
(Damages) and Benefits in Millions of Dollars

Model Screen Type	Cold		Cool		Warm		Rough		None		Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
Equilibrium Models											
GF1 High	(2,299,040)	($2,048)	1,450,242	$1,905	464,854	$192	377,211	$534	6,733	–	$584
GF1 Primary	(2,537,112)	($2,166)	849,823	$305	1,305,773	$1,381	366,201	$561	15,315	–	$81
GF1 Low	(2,759,546)	($2,268)	449,165	($608)	1,789,954	$2,090	423,834	$591	96,594	–	($195)
GI1 High	(964,448)	($1,205)	162,135	$329	489,732	$730	305,847	$336	6,733	–	$191
GI1 Primary	(1,965,543)	($1,724)	745,538	$472	875,839	$903	337,605	$428	6,561	–	$80
GI1 Low	(2,202,512)	($1,799)	279,334	($704)	1,519,077	$1,798	309,113	$462	94,988	–	($243)

Model Screen Type	Cold		Cool		Warm		Rough		None		Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
Equilibrium Models											
OS1 High	(2,032,024)	($1,683)	1,130,044	$1,263	576,575	$364	321,671	$432	6,733	--	$377
OS1 Primary	(2,275,028)	($1,904)	476,188	($358)	1,474,973	$1,668	308,552	$499	15,315	--	($95)
OS1 Low	(2,608,244)	($1,943)	265,804	($998)	1,794,087	$2,091	434,450	$496	113,904	--	($354)
UK1 High	(1,094,780)	($1,039)	407,863	$575	295,892	$312	384,292	$235	6,733	--	$82
UK1 Primary	(3,037,818)	($2,473)	697,951	$60	1,526,839	$1,726	746,236	$603	66,693	--	($85)
UK1 Low	(2,240,124)	($1,627)	537,938	($493)	1,334,726	$1,413	339,928	$365	27,531	--	($342)

assumptions, the dollar values successively decrease. In each case, the high tolerance specification returns estimated benefits. Using the high specification, the estimated benefits range from $82 million for the UK1 model to $584 million for the GF1 model. The primary specifications for GF1 and GI1 result in estimated benefits; whereas the primary specifications for OS1 and UK1 result in estimated damages. In all cases, the low tolerance specification results in estimated damages. The OS1 model shows the greatest damages of all the models ($354 million), followed thereafter by the UK1 model ($342 million), the GI1 model ($243 million), and the GF1 model ($195 million).

The greatest changes in dollar value relative to the primary thermal tolerance specification appear for the high thermal tolerance specifications. Relative to the primary thermal tolerance specification, the dollar values rise considerably across all of the equilibrium models. The increases relative to the primary specification range from $111 million for the GI1 model to $503 million for the GF1 model. For the low thermal tolerance specifications, dollar values consistently fall relative to the primary thermal tolerance specification. The GI1 model ($323 million) shows the largest reduction in dollar value relative to the primary specification followed thereafter by the GF1 model ($276 million), the OS1 model ($259 million), and the UK1 model ($257 million).

4.4.2 Transient Models

Exhibit 4-7 displays the changes in acres and dollar values for the two transient models (TR1 and TR2). Results from the high, primary, and low thermal tolerance specifications are presented. The reductions in best-use cold-water acreage become successively smaller, moving from the low- to high-thermal tolerance specifications, as do the increases in best-use warm-water acreage. The increases in best-use cool-water acreage follow this same trend for the TR2 model, but the TR1 model shows increases under the low (0.6 million) and high (1.6 million) thermal tolerance specification and reveals a decrease (0.1 million) under the primary thermal tolerance specification. The changes in best-use rough acreage vary across the two models.

Similar to the results exhibited by the equilibrium models, benefits are estimated for the transient models under the high thermal tolerance specification. The TR1 model has benefits of $467 million and the TR2 model has benefits of 238 million under the high thermal tolerance specification. Damages are estimated for both the transient models using the primary and low thermal tolerance specifications. Damages under the low thermal tolerance specification range from $339 million for the TR1 model to $402 million for the TR2 model. Relative to the primary thermal tolerance specification, the changes in dollar value are greater under the high specification than the low specification. Increases in dollar value relative to the primary thermal tolerance specification range from $504 million for the TR2 model to $787 million for the TR1 model; while reductions in dollar value relative to the primary thermal tolerance specification range from $19 million for the TR1 model to $136 million for the TR2 model.

Exhibit 4-7
High, Primary, and Low Thermal Tolerance Results for Primary Fishing-Day Values
(Damages) and Benefits in Millions of Dollars

Model	Cold		Cool		Warm		Rough		None		Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damage s) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
Transient Models											
TR1 High	(2,989,579)	($2,594)	1,635,027	$2,166	567,154	$289	780,664	$605	6,733	--	$467
TR1 Primary	(1,409,421)	($1,290)	(90,838)	($805)	1,132,970	$1,467	360,728	$308	6,561	--	($320)
TR1 Low	(3,585,326)	($2,738)	642,505	($549)	2,017,010	$2,283	782,695	$665	143,115	--	($339)
TR2 High	(2,291,924)	($2,171)	706,625	$908	826,956	$966	751,609	$535	6,733	--	$238
TR2 Primary	(3,321,153)	($2,741)	841,548	$66	1,654,019	$1,792	810,271	$617	15,315	--	($266)
TR2 Low	(3,356,782)	($2,563)	432,411	($873)	2,076,737	$2,409	706,811	$625	140,823	--	($402)

4.5 FISH HABITAT DESIGNATIONS

Fish screening matrices were used for the fish species in this study across all the 48 contiguous United States. The thermal model uses the screens to designate fish habitat by state. A value of one in a matrix position indicates that a particular fish species is present in a specific state and a zero indicates the absence of the fish type. The presence of a species was decided by consulting The Audubon Society: Field Guide to North American Fishes, Whales & Dolphins (Boschung, et al., 1983) and the 1985 Survey of Fishing, Hunting, and Wildlife Associated Recreation (U.S. DOI/FWS, 1988). The purpose of this sensitivity analysis is to explore the effects of the screen designs on the results of the economic model. The results discussed in Chapters 2 and 3 are for the primary specification. The primary specification uses a narrow screen to assign fish presence and absence. In this sensitivity analysis, results using a modified wide screen are presented and then compared with the results using the narrow screen.

The narrow screen is based solely on the Audubon Guide's delineation of natural fish habitat. The descriptions and maps within the guide were examined to determine whether a state contained a given fish. If an illustration indicated a ten percent or greater coverage in a state a value of one was assigned to the matrix position. The term narrow refers to the Audubon Guide's relatively conservative estimate of fish habitat.

The wide screen is based both on the narrow screen and data from the 1985 National Survey of Fishing, Hunting, and Wildlife Associated Recreation (U.S. DOI/FWS). The 1985 National Survey groups fish into sets based on identified similarities, with each set containing one to four fish species. Preliminary screens were developed for each of the sets based on information concerning catch information by state. The screens developed using this method typically encompass larger areas for fish species than those of the narrow screen. There are two primary explanations for the wider coverage. First, the survey data include areas where fish were introduced, while the Audubon Guide only clearly defines natural fish habitat or long-established presence of a species. Even if only one of the fish species in a set was actually caught in the state, the state would be designated a habitat for all species in the set. For this reason, the survey-based data are used as the basis for designated a state as habitat only if two or more species in the fish set are present. This approach is adopted to minimize the chance of overestimating actual fish coverage. Under this criterion all of the cool-water fish and most of the warm-water data were used.

The wide screens were incorporated into the thermal model structure and runs were produced for four equilibrium (GF1, GI1, OS1, and UK1) and two transient (TR1 and TR2) climate change models. The results from these sensitivity analyses are discussed in the following sections. The discussion emphasizes the way in which these modifications affect the output of the economic model.

4.5.1 Equilibrium models

Exhibit 4-8 presents the results from the fish screen sensitivity analysis using the primary fishing-day value specification for the four equilibrium models (GF1, GI1, OS1, and UK1). Changes in acres and changes in dollar value are presented by thermal category for both the narrow and wide screens. Several interesting changes occur when the wider screens are adopted. In particular, the mixed results in terms of signs (damages and benefits) that are observed when the equilibrium models use the narrow screen disappear when the wide screen is used. The climate scenarios consistently predict damages across all models.

The wide screen increases the number of best-use cool- and warm-water acres in the baseline model. Greater damages in the wide scenario are the result of larger shifts in best-use cool-water acres to warm-water acres relative to the narrow scenario. The value associated with the loss of cool-water fishing days outweighs that of the gain in warm-water fishing days. In all of the model runs, the switch from the narrow to wide screen has little impact on the changes in best-use cold-water acreage. Changes in best-use cool-water acreage are positive for all of the model runs in the primary narrow configuration. When the wide screen is adopted, the changes in best-use cool-water acreage fall for all models relative to the primary narrow configuration. In the case of the GI1 and OS1 models, these decreases actually result in reductions in cool-water acreage relative to the baseline. Best-use warm-water acreage increases are larger for the wide screen specifications than those for the narrow specification across all of the models. It is important to note that the wide screen, as constructed, has the drawback of underestimating initial best-use cold-water acres since the ranges for salmon and trout were not extended beyond the "natural" ranges indicated in the Audubon guide. Consequently, the criterion of requiring two or more species to be observed in the 1985 survey data in order to designate additional habitat may be too strict. The inclusion of additional best-use cold acres could result in higher damages than presented in this section. Higher damages would occur if temperature increases in the model shifted the additional best-use cold-water acres to a lower-valued best use.

Using the wide screen, all four models generate damages. As was the case using the narrow screen, the OS1 and UK1 models predict damages under the wide screen but they have increased by at least a factor of five (from $95 million and $85 million respectively to $574 million and $500 million). While these models predict the largest damages, results from the GF1 and GI1 models experience the largest changes in the switch from the narrow to the wide screen. Benefits of $80 million and $81 million are predicted for the GF1 and GI1 models, respectively, under the narrow screen, but damages of $443 million and $451 million are estimated under the wide screen.

Relative to the primary narrow screen specification, the GI1 and GF1 models yield the higher changes ($531 million, $524 million) as the dollar values decrease from benefits of approximately $80 and $81 million to damages of $451 and $443 million respectively. The OS1

Exhibit 4-8
Narrow and Wide Screen Results for Primary Fishing-Day Values
(Damages) and Benefits in Millions of Dollars

Model	Cold		Cool		Warm		Rough		None		Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damage s) or Benefits	Change in Acres	(Damages or Benefits	(Damages) or Benefits
Equilibrium Models											
GF1 Narrow	(2,537,112)	($2,166)	849,823	$305	1,305,773	$1,381	366,201	$561	15,315	--	$81
GF1 Wide	(2,706,942)	($2,362)	308,146	($1,868)	2,398,796	$3,110	0	$677	0	--	($443)
GI1 Narrow	(1,965,543)	($1,724)	745,538	$472	875,839	$903	337,605	$428	6,561	--	$80
GI1 Wide	(1,437,896)	($1,607)	(547,707)	($2,144)	1,978,870	$2,803	0	$497	6,733	--	($451)
OS1 Narrow	(2,275,028)	($1,904)	476,188	($358)	1,474,973	$1,668	308,552	$499	15,315	--	($95)
OS1 Wide	(2,489,647)	($2,097)	(16,500)	($2,370)	2,499,414	$3,285	0	$608	6,733	--	($574)
UK1 Narrow	(3,037,818)	($2,473)	697,951	$60	1,526,839	$1,726	746,236	$603	66,793	--	($85)
UK1 Wide	(3,291,316)	($2,675)	645,046	($1,877)	2,639,536	$3,307	0	$746	6,733	--	($500)

Model	Cold		Cool		Warm		Rough		None		Total
	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damage s) or Benefits	Change in Acres	(Damages or Benefits	(Damages) or Benefits
Transient Models											
TR1 Narrow	(1,409,421)	($1,290)	(90,838)	($805)	1,132,970	$1,467	360,728	$308	6,561	--	($320)
TR1 Wide	(1,569,090)	($1,801)	188,300	($574)	1,374,057	$1,884	0	$564	6,733	--	$73
TR2 Narrow	(3,321,153)	($2,741)	841,548	$66	1,654,019	$1,792	810,271	$617	15,315	--	($266)
TR2 Wide	(3,461,683)	($4,647)	778,553	$394	2,676,397	$3,732	0	$1,524	6,733	--	$1,003

($479 million) and UK1 ($415 million) models also show large reductions relative to the dollar value estimated for the primary narrow specification.

4.5.2 Transient Models

Exhibit 4-8 presents the results from the fish screen sensitivity analysis using the primary fishing-day value specification for the two transient models (TR1 and TR2). Changes in acres and changes in dollar value are presented by thermal category for both the narrow and wide screens. For both the transient models, the changes in dollar values switch from damages estimates using the narrow screen to benefits estimates using the wide screen.

For both the transient models, the wide screen specification yields higher losses in best-use cold acreage relative to the narrow screen specification. Comparing best-use cool and warm acreage changes for the narrow and wide screens, best-use cool acres increase for the TR1 model and decrease for the TR2 model using the wide screen and best-use warm-water acreage increases for both the TR1 model and the TR2 model. Changes in best-use rough water acres switched from increases of 360,728 and 810,271 acres with the narrow screen to no change for TR1 and TR2 models with the wide screen.

The TR1 model is the less volatile model of the two transient models because it predicts smaller expected impacts in the near future. In contrast, the TR2 amplifies the additional acreage included in the wide screen predicting larger effects over time. The wide screen has more initial warm-water acreage, making warm-water acreage a better substitute for cool and cold-water acreage than it is under the narrow screen. This leads to more benefits as the temperature increases in the TR2 model. The effect is noticeable throughout most of the categories shown in Exhibit 4-8 aside from the cool category where the ratio of the changes is close for both models.

With the wide screen, the TR1 model shows significantly lower benefits ($73 million) than the TR2 model ($1,003 million). Relative to the primary narrow specification results, the TR1 model reveals an increase in value of $393 million and the TR2 model exhibits an increase in value of $1,269 million using the wide screen.

The results using the high and low fishing-day value specifications for the narrow and wide screens are presented for the equilibrium and transient models in Exhibit 4-9 and Exhibit 4-10. These exhibits are presented for comparison purposes only.

Exhibit 4-9
Narrow and Wide Screen Results for Low Fishing-Day Values[1]
(Damages) and Benefits in Millions of Dollars

Model	Cold		Cool		Warm		Rough		None		Total
Screen Type	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
Equilibrium Models											
GF1	(2,537,112)	($2,166)	849,823	$213	1,305,773	$1,381	366,201	$610	15,315	--	$38
GF1	(2,706,942)	($2,362)	308,146	($1,301)	2,398,796	$3,110	0	$736	0	--	$183
GI1	(1,965,543)	($1,724)	745,538	$329	875,839	$903	337,605	$466	6,561	--	($26)
GI1	(1,437,896)	($1,607)	(547,707)	($1,493)	1,978,870	$2,803	0	$540	6,733	--	$243
OS1	(2,275,028)	($1,904)	476,188	($249)	1,474,973	$1,668	308,552	$543	15,315	--	$57
OS1	(2,489,647)	($2,097)	(16,500)	($1,651)	2,499,414	$3,285	0	$662	6,733	--	$199
UK1	(3,037,818)	($2,473)	697,951	$42	1,526,839	$1,726	746,236	$655	66,793	--	($50)
UK1	(3,291,316)	($2,675)	645,046	($1,307)	2,639,536	$3,307	0	$811	6,733	--	$135
Transient Models											
TR1	(1,409,421)	($1,290)	(90,838)	($561)	1,132,970	$1,467	360,728	$335	6,561	--	($49)
TR1	(1,569,090)	($1,801)	188,300	($400)	1,374,057	$1,884	0	$613	6,733	--	$296
TR2	(3,321,153)	($2,741)	841,548	$46	1,654,019	$1,792	810,271	$671	15,315	--	($232)
TR2	(3,461,683)	($4,647)	778,553	$274	2,676,397	$3,732	0	$1,657	6,733	--	$1,017

[1] Fishing-day values under the low specification are: cold ($41.75), cool ($29.08), and warm ($29.08), and rough ($24.96).

Exhibit 4-10
Narrow and Wide Screen Results for High Fishing-Day Values[1]
(Damages) and Benefits in Millions of Dollars

Model	Cold		Cool		Warm		Rough		None		Total
Screen Type	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
Equilibrium Models											
GF1 Narrow	(2,537,112)	($2,383)	849,823	$305	1,305,773	$1,381	366,201	$505	15,315	--	($191)
GF1 Wide	(2,706,942)	($2,599)	308,146	($1,868)	2,398,796	$3,110	0	$609	0	--	($747)
GI1 Narrow	(1,965,543)	($1,897)	745,538	$472	875,839	$903	337,605	$386	6,561	--	($136)
GI1 Wide	(1,437,896)	($1,767)	(547,707)	($2,144)	1,978,870	$2,803	0	$447	6,733	--	($661)
OS1 Narrow	(2,275,028)	($2,094)	476,188	($358)	1,474,973	$1,668	308,552	$449	15,315	--	($335)
OS1 Wide	(2,489,647)	($2,307)	(16,500)	($2,370)	2,499,414	$3,285	0	$548	6,733	--	($844)
UK1 Narrow	(3,037,818)	($2,720)	697,951	$60	1,526,839	$1,726	746,236	$542	66,793	--	($393)
UK1 Wide	(3,291,316)	($2,943)	645,046	($1,877)	2,639,536	$3,307	0	$671	6,733	--	($842)

Model	Cold		Cool		Warm		Rough		None		Total
Screen Type	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	Change in Acres	(Damages) or Benefits	(Damages) or Benefits
Transient Models											
TR1 Narrow	(1,409,421)	($1,420)	(90,838)	($805)	1,132,970	$1,467	360,728	$277	6,561	--	(480)
TR1 Wide	(1,569,090)	($1,981)	188,300	($574)	1,374,057	$1,884	0	$508	6,733	--	($164)
TR2 Narrow	(3,321,153)	($3,015)	841,548	$66	1,654,019	$1,792	810,271	$556	15,315	--	($602)
TR2 Wide	(3,461,683)	($5,111)	778,553	$394	2,676,397	$3,732	0	$1,372	6,733	--	$386

[1] Fishing-day values under high specification are: cold ($45.93), cool ($41.75), warm ($29.08), and rough ($24.96).

4.6 WARM-WATER FISHING BEHAVIOR

The economic model uniformly treats and values additions (reductions) in recreational fishing days within each of the acreage categories as new or expanded (decreased) recreational opportunities. The economic model takes the baseline division of best-use acreage and then modifies this distribution according to the predicted thermal dynamics. The modifications are also shaped by the assumption that cold-water fishing is preferred to cool-water fishing which is preferred to warm-water fishing and so on. This chain of logic drives the designation of best-use acreage, and it is important to acknowledge that all best-use acreage designations are mutually exclusive. Thus, any changes from one acreage category to another are treated as transfers in recreational opportunities. In doing so, it is possible that the impacts on recreational fishing behavior are overstated by the economic model. This sensitivity analysis addresses the potential for the model to overestimate the changes in warm-water fishing days established under the various climate change scenarios.

The potential for overcounting follows from the best-use designation of the model where it is always assumed that cold-water and cool-water fishing are preferred to warm-water fishing. It is evident that in many states these two types of fishing coincide and that waters of states jointly provide opportunities for both activities. In short, the types of recreational fishing service flows supplied by acreage may not always be mutually exclusive. In states where waters jointly provide opportunities, the economic model will tend to give more weight to the recreational service flows provided by the cold-water acreage than those provided by the warm-water acreage by virtue of the best-use designation process. When the model shifts acreage from the cold-water and cool-water best-use acreage categories to the warm-water category, increases in the number of warm-water fishing days result, and in turn there are valued by the model as changes in opportunities or new fishing days. In cases where warm-water fishing is already common place, such changes may not truly reflect the extent of new recreational opportunities but rather may overestimate the availability of such opportunities.

Using activity day data from the U.S. Department of Interior (1988) 1985 Survey of Fishing, Hunting, and Wildlife Associated Recreation Survey, the South Atlantic and Gulf Coast Region was identified as an area where overcounting might potentially occur. The U.S. Department of Interior (1993) has published a 1991 Survey of Fishing, Hunting, and Wildlife Associated Recreation. However, this more recent survey does not break out fishing days by activity type by state. The 1985 Survey provides estimates of the number of person-days associated with cold-water, cool-water, warm-water, anadromous, warm-water, and saltwater fishing. The states comprising the region include: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Texas. In each of these states warm-water fishing days were the dominant type of fishing activity reported. For example, the percentage of freshwater fishing days devoted to warm-water fishing in this region range from a low of 56 percent in Tennessee to a high of 86 percent in Mississippi.

To test the sensitivity of the economic modelling results with regards to the treatment of warm-water fishing days, the function that calculates the change in warm-water fishing days was modified. This adaptation of the model was based on the assumption that no increases in warm-water fishing days will occur in the South Atlantic and Gulf Coast Regions due to global climate change. It is important to note that this is an extreme assumption, for it is likely that some new warm-water fishing days will result. New warm-water days are likely to result as some anglers substitute for lost cold-water and cool-water fishing opportunities. The adapted model was run for four equilibrium scenarios (GF1, GI1, OS1, and UK1) and two transient scenarios (TR1 and TR2). The output from these modified runs using the primary, high, and low fishing day value specifications appears in Exhibits 4-11, 4-12, and 4-13, respectively.

The effects of these changes are illustrated in the results presented in these exhibits. By limiting the extent of changes in the South Atlantic and Gulf Coast region, predicted changes in warm-water fishing days fall across all scenarios. In turn, the predicted benefits (damages) fall (increase) or stay the same in size. For the primary specification, the changes in total dollar value of recreational fishing days range from no change in the GI1 and TR2 scenarios to reductions of approximately $15 million in the GF1, OS1, and UK1 scenarios. Similar results are exhibited in the high and low fishing-day value specification tables where no changes in total value result in the GI1 and TR2 scenarios and the higher decreases in total dollar value occur in the UK1 (17,16), GF1 (15,15), and OS1 (15,14) scenarios.

Exhibit 4-11
Sensitivity Analysis of the Model's Treatment of Warm-Water Fishing Days

Scenario	Warm Days (1,000s)	Total Dollar Value (Millions)	Warm Days (1,000s)	Total Dollar Value (Millions)	Change in Total Dollar Value (Millions)
Primary Specification Changes			Modified Specification Changes		
GF1	47,488	81	46,985	67	14
GI1	31,064	80	31,064	80	0
OS1	57,337	(95)	56,827	(110)	15
UK1	59,338	(85)	58,784	(101)	16
TR1	50,441	(320)	50,189	(327)	7
TR2	61,621	(266)	61,621	(266)	0

Exhibit 4-12
Sensitivity Analysis of the Model's Treatment of Warm-Water Fishing Days

Scenario	Warm Days (1,000s)	Total Dollar Value (Millions)	Warm Days (1,000s)	Total Dollar Value (Millions)	Change in Total Dollar Value (Millions)
High Specification Changes			Modified Specification Changes		
GF1	47,488	(191)	46,985	(206)	15
GI1	31,064	(136)	31,064	(136)	0
OS1	57,337	(335)	56,827	(350)	15
UK1	59,338	(393)	58,784	(409)	16
TR1	50,441	(480)	50,189	(487)	7
TR2	61,621	(602)	61,621	(602)	0

Exhibit 4-13
Sensitivity Analysis of the Model's Treatment of Warm-Water Fishing Days

Scenario	Warm Days (1,000s)	Total Dollar Value (Millions)	Warm Days (1,000s)	Total Dollar Value (Millions)	Change in Total Dollar Value (Millions)
Low Specification Changes			Modified Specification Changes		
GF1	47,488	38	46,985	23	15
GI1	31,064	(26)	31,064	(26)	0
OS1	57,337	57	56,827	43	14
UK1	59,338	(50)	58,784	(67)	17
TR1	50,441	(49)	50,189	(56)	7
TR2	61,621	(232)	61,621	(232)	0

4.7 COLD-WATER SUBSTITUTABILITY

The economic model currently assumes costless transitions across all categories of best-use fishing acreage. In truth, natural conditions may not permit such transitions to occur without costs such as time delays or species shifts. The purpose of this sensitivity analysis is to assess the effects of altering the costless transition assumption. Specifically, this sensitivity analysis addresses the transfer of cold-water acreage to cool, warm, and rough best-use fishing acreage. In practice, the evaluation of cold-water acreage substitutability takes quite an extreme posture. It is assumed that best-use cold-water acreage losses due to thermal changes are effectively lost recreational service flows. In other words, these acreage losses are not transferable in any way. The model is adapted to effectively remove these acres from the analysis rather than to move these acres to the best-use cool-water, warm-water, or rough acreage categories.

To test the sensitivity of the economic modelling results with regards to the treatment of cold-water acreage, the model was revised so that any changes from baseline best-use cold-water acreage that resulted from the global climate change scenarios are shifted to an acreage category specified as the none category. This category is termed the none category, for it is assumed that no recreational fishing service flows are provided by this acreage. For states with no baseline best-use cold fishing acreage, the modelling functions were not altered and the scenarios were run as usual. For states with baseline best-use cold acreage, it was assumed that no changes from baseline occurred in the cool-water, warm-water, and rough acreage categories. This assumption was necessary because of the difficulty of disentangling the determinants of flows of acreage from one category to another. These adaptations of the model were based on the assumption that cold-water acreage would not readily move to the other categories of fishing acreage. This is an extreme assumption, for it is not likely that all these acres would be entirely lost. In addition, it is also likely that shifts from other types of acreage categories would also be limited by natural and other forces. The adapted model was run for four equilibrium scenarios (GF1, GI1, OS1, and UK1) and two transient scenarios (TR1 and TR2). The output from these modified runs using the primary, high, and low fishing-day value specification appear in Exhibits 4-14, 4-15, and 4-16, respectively.

The effects of these changes to the model are made clear in the results presented in these exhibits. By eliminating the transfer of best-use cold acreage to other best-use acreage designations, the damages of global climate change are heightened. Losses in best-use cold-water acreage and their associated recreational service flows are not transferable to other acreage designations thereby eroding the possibility for substitution across fishing activities by anglers. In turn, the predicted benefits (damages) fall (increase) across all of the scenarios. In the primary specification, the decreases in total dollar value of recreational fishing days range from approximately \$508 million in the TR1 scenario to \$1,044 million in the UK1 and TR2 scenarios. Comparing the magnitude of the results of the primary and modified scenarios, the influence of the reductions in the number of cool-water fishing days is evident. It appears that in many of the scenarios cold-water fishing acreage is transferred to the cool-water acreage category rather than to the other categories of fishing acreage. These cool-water fishing days are highly valued by the model and this is reflected in the changes in dollar value of the primary specification scenarios. By eliminating the occurrence of such shifts, the substitution possibilities across fishing activities are markedly limited and the resulting damages measured in fishing-day values are accentuated. Similar patterns surface in the output from the high and low specifications. For the high specification, the decreases in the total dollar value of recreational fishing days ranges from approximately $468 million in the TR1 scenario to $970 million in the UK1 scenario. Whereas for the low specification, decreases in the total dollar value of recreational fishing days range from approximately $167 million in the TR1 scenario to $346 million in the UK1 scenario.

4.8 POTENTIAL IMPACTS ON RECREATIONAL FISHING FROM CHANGES IN RUNOFF

Climate change can have a significant impact on runoff due to changes in precipitation patterns and watershed characteristics. In this section, the effects of climate change on runoff are characterized. Then, potential economic losses on recreational fishing due to changes in runoff are evaluated. This section is included because it addresses the uncertainties associated with modelling recreational fishing responses under climate change scenarios. In contrast to the other analyses presented in this chapter, no modifications were made to the model structure nor were results generated for scenarios using alternative specifications. Rather, the discussion presented here is for illustrative purposes and seeks to emphasize the significance of runoff assumptions when modelling the effects of climate change scenarios.

4.8.1 Climate Change Effects on Runoff

Quantification of the effects of climate change on stream runoff for the entire United States is difficult. We performed a literature review on this subject to quantify this effect for the different physiographic regions (see Exhibit 4-17). However, as shown in Exhibit 4-17, wide ranges of increases and decreases in runoff due to climate change are documented. This result is in part due to the use of different modelling assumptions in the climate change models, as well as the geographical location and site characteristics of each study. Nevertheless, based on the current state-of-the-art in runoff modelling of climate change effects, the following can be concluded from these studies:

Exhibit 4-14
Sensitivity Analysis of the Model's Treatment of Cold-Water Acreage Transitions

Scenario	Rough Days (1,000s)	Warm Days (1,000s)	Cool Days (1,000s)	Total Dollar Value (Millions)	Rough Days (1,000s)	Warm Days (1,000s)	Cool Days (1,000s)	Total Dollar Value (Millions)	Change in Total Dollar Value (Millions)
Primary Specification Changes					**Modified Specification Changes**				
GF1	24,448	47,488	7,307	81	16,651	78,587	(45,714)	(905)	986
GI1	18,660	31,064	11,300	80	12,862	54,254	(28,834)	(619)	699
OS1	21,746	57,337	(8,572)	(95)	14,923	87,262	(58,153)	(1,018)	923
UK1	26,257	59,338	1,428	(85)	18,520	91,233	(54,949)	(1,129)	1044
TR1	13,427	50,441	(19,272)	(320)	9,274	65,218	(48,860)	(828)	508
TR2	26,894	61,621	1,576	(266)	18,713	97,608	(61,329)	(1,310)	1044

Exhibit 4-15
Sensitivity Analysis of the Model's Treatment of Cold-Water Acreage Transitions

Scenario	Rough Days (1,000s)	Warm Days (1,000s)	Cool Days (1,000s)	Total Dollar Value (Millions)	Rough Days (1,000s)	Warm Days (1,000s)	Cool Days (1,000s)	Total Dollar Value (Millions)	Change in Total Dollar Value (Millions)
High Specification Changes					Modified Specification Changes				
GF1	24,448	47,488	7,307	(191)	16,651	78,587	(45,714)	(1,110)	919
GI1	18,660	31,064	11,300	(136)	12,862	54,254	(28,834)	(778)	642
OS1	21,746	57,337	(8,572)	(335)	14,923	87,262	(58,153)	(1,199)	864
UK1	26,257	59,338	1,428	(393)	18,520	91,233	(54,949)	(1,363)	970
TR1	13,427	50,441	(19,272)	(480)	9,274	65,218	(48,860)	(948)	468
TR2	26,894	61,621	1,576	(602)	18,713	97,608	(61,329)	(1,555)	953

Exhibit 4-16
Sensitivity Analysis of the Model's Treatment of Cold-water Acreage Transitions

Scenario	Rough Days (1,000s)	Warm Days (1,000s)	Cool Days (1,000s)	Total Dollar Value (Millions)	Rough Days (1,000s)	Warm Days (1,000s)	Cool Days (1,000s)	Total Dollar Value (Millions)	Change in Total Dollar Value (Millions)
Low Specification Changes					Modified Specification Changes				
GF1	24,448	47,488	7,307	38	16,651	78,587	(45,714)	(293)	331
GI1	18,660	31,064	11,300	(26)	12,862	54,254	(28,834)	(228)	202
OS1	21,746	57,337	(8,572)	57	14,923	87,262	(58,153)	(251)	308
UK1	26,257	59,338	1,428	(50)	18,520	91,233	(54,949)	(396)	346
TR1	13,427	50,441	(19,272)	(49)	9,274	65,218	(48,860)	(216)	167
TR2	26,894	61,621	1,576	(232)	18,713	97,608	(61,329)	(495)	263

- Runoff modelling of climate change scenarios, considering changes in temperature, precipitation, and basin characteristics, show significant effects on the seasonal amounts of runoff. For instance, seasonal variations in runoff are more important than annual changes because of the different fish responses to runoff conditions under different seasons.

- Changes in temperature and rainfall have a significant effect on the seasonal distribution of runoff. Winter runoff may increase while spring and summer runoff may decrease due to a decrease in snow accumulations. For instance, Lettenmaier and Gan (1990) found that in watersheds dominated by spring runoff from snowmelt, such as the Sacramento and San Joaquin basins, winter runoff increased twice as much, while spring and summer runoff decreased. This shift in runoff can be more important than the overall annual change in runoff due to the impact on the available runoff in the summer, which is a critical period for recreational fishing (Johnson and Adams, 1988). In addition, increases in the frequency of high flows during spring can have detrimental effects because they can scour spawning areas.

- Most of the studies summarized in Exhibit 4-17 only consider changes in temperature and precipitation. Most recently, Kite (1993) also considered changes in watershed characteristics such as vegetation, biomass production, soil processes, erosion, and slope stability among others. For instance, increases in CO_2 can alter the photosynthesis and transpiration of vegetation, decreasing stomatal conductance and increasing the efficiency of the plant, making more water available for runoff. Kite (1993) found that under a 2 X CO_2 scenario the frequency of high flows increased and the snowpack decreased significantly.

4.8.2 Implications of Runoff Changes in Fish Recreational Values

There are some studies in the literature addressing the recreational value of streamflow for different regions of the country. Among those, Hansen and Hallam (1991) provided marginal values per acre-foot of water for recreational fishing. Marginal values were estimated for 99 river subbasins for trout and bass. Exhibit 4-18 shows the interquantile ranges for the marginal values per acre-foot of water from the Hansen and Hallam (1991) study. Johnson and Adams (1988) estimated benefits for the recreational fishing of steelhead in the John Day river in Oregon. A value of $2.36 (in 1987 dollars) for an additional acre-foot of water in the summer was estimated. Values of -$0.32 and $0.18 were estimated for the spring and winter respectively.

Exhibit 4-17
Effects of Global Climate Change on Runoff

Basin		Model	Scenario		Results		References and Comments
			ΔT[1](C)	Δppt[2] (%)	ΔRunoff (%)		
Texas: Pease River Basin			+3 +3	+10 -10	+35 -50		Nemec & Schaake (cited in Frederick & Gleick, 1988)
Texas: Gulf Region			+2	-10	-49.8 (supply)		Revelle and Waggoner (1983)
Southeastern quadrant US	Humid Ea. Arid West			-10 -10	-20 -35		Schaake (cited in Poff, 1992)
California: Sacramento Basin					Summer	Winter	Gleick (1987)
		GFDL[3]	ΔT only ΔT ΔT	 relative Δppt absolute Δppt	-50 -48 -48	+26 +34 +66	
		GISS[4]	ΔT only ΔT ΔT	 relative Δppt absolute Δppt	-68 -53 -40	+38 +81 +33	
		NCAR[5]	ΔT only ΔT	 absolute Δppt	-40 -30	+17 +16	

Basin	Model	Scenario		Results			References and Comments
		ΔT[1](C)	Δppt[2] (%)	ΔRunoff (%)			
California: Sacramento Basin	Other Scenarios	+2	0	-22	+8		Gleick (1987)
		+2	-10	-32	-9		
		+2	-20	-42	-24		
		+2	+10	-12	+25		
		+2	+20	-1	+44		
		+4	0	-62	+34		
		+4	-10	-68	+14		
		+4	-20	-73	-4		
		+4	+10	-55	+54		
		+4	+20	-49	+75		
		+2	-10	-18			Gleick, 1986, 1987 (cited in Frederick & Gleick, 1988)
		+2	+10	+12			
White River	NWSRFS[8]			Spring	Fall	Ann	Nash & Gleick 1993 Note: Spring={Apr, May, Jun} Fall={Oct, Nov, Dec}
		+4	-20	-30	-17	-26	
		+4	-10	-21	-8	-18	
		+4	0	-11	+1	-9	
		+4	+10	+1	+11	+1	
		+4	+20	+14	+21	+12	
Colorado: Upper Colorado River Basin		+2	-10	-40			Revelle and Waggoner (1983)
		+2	+10	-18			
Missouri Region		+2	-10	-63.9 (supply)			Revelle and Waggoner (1983)

Basin		Model	Scenario		Results	References and Comments
			ΔT^1(C)	Δppt^2 (%)	ΔRunoff (%)	
Great Basin (NV, UT, CA) (4 basins)	California: West Fork of Carson River		-2 -2 +2 +2	+25 +10 -10 -25	+40 +20 -17 -38	Flaschka et al., (1987)
	Nevada: Martin Creek		-2 -2 +2 +2	+25 +10 -10 -25	+76 +35 -28 -51	
	Utah-Wyoming: Bear River		-2 -2 +2 +2	+25 +10 -10 -25	+46 +22 -22 -42	
	Sevier River		-2 -2 +2 +2	+25 +10 -10 -25	+68 +31 -25 -50	
Upper Rio Grande			+2	-10	-30	Stockton, et al. (in Flashka, et al., 1987)
Rio Grande			+2	-10	-76	Stockton & Boggess (cited in Revelle and Waggoner, 1983)
Rio Grande Water Region			+2	-10	-75.5 (supply)	Revelle and Waggoner (1983)

Basin	Model	Scenario		Results	References and Comments
		ΔT[1](C)	Δppt[2] (%)	ΔRunoff (%)	
Delaware River Basin		+2 +2 +2 +2 +2	-20 -10 0 +10 +10	-51 -32 -14 +8 +31	McCabe & Ayers (in Carpenter, et al., 1992) ***Note: Seasonal runoff change, especially in cold northern portion of basin.***
Delaware River Basin	GFDL GISS OSU[6]	+4 +4 +4		-7 -39 +9	Ayers, et al., (1993)
Great Lakes Basin	GISS GFDL	+(4.3-4.8) +(3.1-3.7)		-10.9 -8.2	Cohen (1986)
Missouri Water Region		+2	-10	-63.9 (supply)	Revelle and Waggoner (1983)
Arkansas-White-Red		+2	-10	-53.8 (supply)	Revelle and Waggoner (1983)
Arid Basin		+1 +1	+10 -10	+50 -50	Nemec & Schaake (in Carpenter, et al., 1992)
Humid Basin		+1 +1	+10 -10	+25 -20	Nemec & Schaake (in Carpenter, et al., 1992)
Canada: Kootenay Basin	CCC GCM[7]: $2*CO_2$(No Stomatal Effect)	+4	+14	+50	Kite (1993)
	CCC GCM: $2*CO^2$ (Stomatal Effect)	+4	+14	+60	

Notes:

[1] ΔT = Temperature change in °C used to model the effects of global climate change.
[2] Δppt = Percent change in precipitation used to model the effects of global climate change.
[3] GFDL = Geophysical Fluid Dynamics Laboratory
[4] GISS = Goddard Institute for Space Studies
[5] NCAR = National Cancer for Atmospheric Research
[6] OSU = Oregon State University
[7] CCC GCM = Canadian Climate Centre Global Circulation Models
[8] NWSRFS = National Weather Service River Forecasting Service

Exhibit 4-18
Marginal Values Per Acre-Foot in 1980 dollars

Quantile	Trout	Bass
25%	1.54	1.35
50% (median)	3.45	3.13
75%	10.50	7.14

4.8.3 Economic Implications of Runoff Changes

Accurate estimation of the economic loss due to changes in runoff would require estimates of seasonal changes in runoff for different climate change scenarios by subbasin for the entire United States. In addition, baseline runoff volumes by basin would be needed for each basin. However, as pointed out before, magnitudes of the runoff changes are not available for the entire nation. In addition, available basin-specific studies, as summarized in Exhibit 4-17, showed a wide range of effects which are mainly due to the climate change model used and the underlying assumptions. Nevertheless, to provide a crude estimate of potential economic losses due to changes in runoff, some simplified assumptions can be made. Rough estimates of volume of annual runoff can be obtained for the entire nation (USGS, 1989). Then, potential runoff changes can be assumed along with marginal values per acre-foot lost to obtain potential economic losses due to changes in runoff.

To estimate economic losses, the following assumptions were adopted:

- a weighted average runoff depth (i.e. the volume of water covering a drainage area to a depth expressed in inches) of 15 inches per year for the entire U.S.,
- a range of 20 percent to 50 percent reduction in runoff during the summer with one quarter of the annual runoff assigned to this period, and
- an economic loss of $3 per acre-foot of water.

The resulting estimated economic loss for recreational fishing could range from $0.4 to $1.0 billion per year. This crude estimate includes many simplifying assumptions and is given only for illustrative purposes. Nevertheless, it is important to point out that the effect of runoff changes due to climate change is an important issue for further consideration. The general conclusion at this point is that climate change could affect seasonal runoff and that decreases in runoff during the summer could lead to significant economic losses in recreational fishing.

4.9 SUMMARY AND CONCLUSION

Chapter 4 presents discussions of seven analyses of the model. These discussions emphasize the role and/or significance of different assumptions and methods in modelling the ecological impacts from climate change. The topics examined include fishing-day values (4.2), climate sensitivity and emissions scenarios (4.3), fish thermal tolerances (4.4), fish habitat designations (4.5), warm-water fishing behavior (4.6), cold-water substitutability (4.7), and runoff (4.8). Within this set of topics, assumptions regarding both ecologic and economic issues are addressed and various pathways of effects on the output of the economic model are explored.

It is difficult to compare and contrast the findings of the different sections, for the proposed modifications to the modelling assumptions vary in nature as do the uncertainties associated with the modified specifications. In particular, the effects of altering ecologic and economic assumptions are likely to have markedly different influences on the output of the model. The ecologic changes are often reflected in shifts in best-use acreage, whereas the economic changes can directly affect participation probabilities or fishing-day values. For some analyses, the relevant sensitivity indicators might be acres, and for others, it might be fishing days or changes in fishing-day values. In some instances, it might be useful to compare the relative variation in size of the different model estimates. In other cases, it might be of more value to compare the absolute variation in size or the variation in signs of the estimates.

For simplicity, Exhibit 4-19 presents the results from six of the seven different analyses in terms of the estimated relative changes in recreational fishing value. These six use the thermal and economic framework based upon Vaughan and Russell. In this context, relative change refers to the difference between the sensitivity analysis estimate and the primary specification estimate of the total dollar value of the ecological change. The relative changes provide some measure of the sensitivity of the primary specification results to the modified assumption of interest. It is important to note that these numbers do not reveal the percentage of the change in value. The total changes in dollar estimates are also presented for review. These numbers should provide some understanding of the magnitude of the shifts in value. By comparing the total changes in dollars for the different scenarios with the primary specification dollar estimates shown in the top portion of the table, it is possible to check the calculation of the relative change and to discover the nature of the transition. Exhibit 4-19 displays the results of the various analyses by global climate modelling scenario. The different specifications examined within the analyses are noted.

The single largest relative change is estimated for the fish habitat designation. The adoption of the wide screen for the TR2 climate scenario results in an increase in value of $1,269 million. Other large relative changes appear in the cold-water substitution analysis with two climate scenarios (TR2 and UK1) showing changes of approximately $1,044 million. Several of the specifications modeled in the cold-water substitution and fish habitat designation analyses reveal relative changes upwards of $500 million. The climate and emissions scenario and the fish thermal tolerance sensitivity analyses show the next greatest levels of sensitivity in terms of relative value changes with most changes falling above $200 million. The fishing-day value sensitivity analysis follows with most changes above $100 million. The warm-water fishing behavior analysis results in the smallest relative changes, with changes ranging from $0 to $17 million. The range of total dollar values across all specifications is very large when compared to the range given on the primary specifications. The later ranged from -$320 million to $81 million but these alternative specifications range from -$1,6 billion to $1 billion in annual impacts.

The runoff impacts presented in Section 4.8 should be considered separately since they were developed outside of the thermal and economic framework used in most of this study. While the estimated runoff impacts are speculative, their large magnitude ($0.4 to 1.0 billion per year) suggests that runoff changes could be a significant, additional element in the impact of climate change on recreational fishing.

In closing, it is important to note that the interpretation of the results from the primary and alternative specifications is critical. The results may indeed be ambiguous since both large damages ($1.6 billion per year) and large benefits ($1 billion per year) can be derived from alternative specifications but it would be a mistake to conclude that "on average" these results cancel and there is no impact. On the contrary, this study suggests that both are possible. Nonetheless, taking the thermal and runoff changes together may tilt the judgment to be made from this study more toward substantial damages. In sum, while the study could appropriately be interpreted as inconclusive about the size and direction of the impacts of climate change on recreational fishing, the study does indicate the possibility of substantial economic damages. In this sense, substantial economic damages to recreational fishing are a contingency. Determining what weight to attach to this contingency given limited information and large uncertainties is a difficult choice for public policymakers. At a minimum, the body of evidence and analysis compiled in this report indicate that this contingency should not be dismissed.

Exhibit 4-19
Sensitivity Analysis Comparison:
Relative Changes in the Dollar Value and the Absolute Total Dollar Value
By Global Climate Change Scenario
(Million Dollars)[1]

Analysis	Specification	Relative Changes						Total Dollar Values					
		GF1	GI1	OS1	UK1	TR1	TR2	GF1	GI1	OS1	UK1	TR1	TR2
Primary Specification	Low Fishing-day Values							38	(26)	57	(50)	(49)	(232)
	Primary Fishing-day Values							81	80	(95)	(85)	(320)	(266)
	High Fishing-day Values							(191)	(136)	(335)	(393)	(480)	(602)
Fishing-day Value	low fishing-day value	(43)	(106)	152	35	271	34	38	(26)	57	(50)	(49)	(232)
	high fishing-day value	(272)	(216)	(240)	(308)	(160)	(336)	(191)	(136)	(335)	(393)	(480)	(602)
Climate Sensitivity	low temperature increment	314	(44)	278	198	250	522	395	36	183	113	(70)	256
	high temperature increment	(642)	(211)	(372)	(666)	55	(296)	(561)	(131)	(467)	(751)	(265)	(562)
Fish Thermal Tolerances	low thermal tolerance	(276)	(323)	(259)	(257)	(19)	(136)	(195)	(243)	(354)	(342)	(339)	(402)
	high thermal tolerance	503	111	472	167	787	504	584	191	377	82	467	238
Fish Habitat Designation	wide screen habitat designation	(524)	(531)	(479)	(415)	393	1,269	(443)	(451)	(574)	(500)	73	1003

Analysis	Specification	Relative Changes						Total Dollar Values					
		GF1	GI1	OS1	UK1	TR1	TR2	GF1	GI1	OS1	UK1	TR1	TR2
Warm-water Fishing Behavior[2]	low values	(15)	0	(14)	(17)	(7)	0	23	(26)	43	(67)	(56)	(232)
	primary values	(14)	0	(15)	(16)	(7)	0	67	80	(110)	(101)	(327)	(266)
	high values	(15)	0	(15)	(16)	(7)	0	(206)	(136)	(350)	(409)	(487)	(602)
Cold-water Acreage Substitution[3]	low values	(331)	(202)	(308)	(346)	(167)	(263)	(293)	(228)	(251)	(396)	(216)	(495)
	primary values	(986)	(699)	(923)	(1044)	(508)	(1044)	(905)	(619)	(1018)	(1129)	(828)	(1310)
	high values	(919)	(642)	(864)	(970)	(468)	(953)	(1110)	(778)	(1199)	(1363)	(948)	(1555)

Notes:

[1] The numbers that appear in this table are expressed in millions of dollars. The parentheses indicate negative numbers. The relative change in value is calculated as follows: total sensitivity analysis estimate - total primary specification estimate. In this context, negative number indicate increased damages, reduced benefits, or conversions from benefits to damages. By comparing the relative change to the absolute number, the nature of the transition can be made clear. The three sets of primary specifications are presented to assist with the interpretation of the warm-water and cold-water sensitivity analyses. Only these analyses present results under all three fishing-day value specifications. For all other analyses, the primary specification is the relevant set of numbers.

[2] The warm-water fishing behavior sensitivity analysis changes the way in which warm-water fishing days are designated in one region of the United States. The high, primary, and low value references here indicate what specifications of fishing-day values are used.

[3] The cold-water acreage substitution sensitivity analysis changes the way in which acreage shifts across categories. The high, primary, and low value references here indicate what specifications of fishing-day values are used.

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APPENDICES A THROUGH F

APPENDIX A

FISH DESCRIPTIONS

Coldwater Fish

Pink Salmon (Oncorhynchus gorbuscha)

Pink Salmon are up to 3'3" in length, blue-green in color above, and silvery-white below. Has large dark ovals spots on back. Pink Salmon are found in waters inshore usually at mid-depth or near the surface. They spawn upstream sometimes far inland and are valued as game fish. Inhabits California, Idaho, Michigan, Minnesota, Oregon, and Washington. Related to the Coho Salmon. (Boschung et al., 389)

Chum Salmon (Oncorhynchus keta)

The Marine variety of the Chum are up to 33" in length, blue-green above, and silvery below. The freshwater variety are bright red with a pale green head. Females are sometimes characterized by green and yellow blotches. The Chum occurs in freshwater streams, rivers, and lakes that contain tributary systems for spawning. Chum inhabit California, Washington, and Oregon. (Boschung et al., 390)

Cutthroat Trout (Salmo clarki)

Cutthroat Trout are up to 30" in length and 41 lbs in weight. They are characterized by a dark olive back, variable color sides from silvery to yellow-orange, and a lighter belly. Cutthroat Trout are valued as a game fish by fisherman. The Cutthroat is common to inshore marine waters; lakes; and coastal, inland, and alpine streams. It can be found in Washington, California, Oregon, Montana, Idaho, Wyoming, Utah, Colorado, New Mexico, Arizona, and Nevada. (Boschung et al., 393)

Mountain Whitefish (Prosopium williamsoni)

The Mountain Whitefish weighs up to four and one half pounds and can grow to twenty-two inches in length. Greenish to blue-gray on back and silvery on sides. The Mountain Whitefish inhabits lakes and streams in Washington, Oregon, California, and Idaho. (Boschung et al., 392)

Coho Salmon (Oncorhynchus kisutch)

The Coho can grow to a length of three feet and three inches, is blue-green with irregular dark spots on the back and silvery-white below. They are a highly prized game fish. Coho inhabit inshore waters and spawn in coastal streams. Coho are found in Washington, Oregon, California, and Idaho. (Boschung et al., 389)

Rainbow Trout (Salmo gairdneri)

Rainbow Trout can be 3'9" in length and just over forty-two pounds. They are characterized by a metallic-blue coloring above, silvery-white coloring below, and small, black spots on the back and sides. The freshwater variety have a distinctive red band on the side and more prominent spots. Rainbow Trout are a valued game fish. Rainbow Trout inhabit lakes and rivers in Arizona, California, Colorado, Connecticut, Idaho, Indiana, Maine, Massachusetts, Michigan, Missouri, Nevada, New Hampshire, New York, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Washington, Wisconsin, and Wyoming. (Boschung et al., 394)

Chinook Salmon (Oncorhynchus tshawytscha)

The Chinook Salmon grows to a maximum of 4'10" in length and 126 pounds. The Chinook has a greenish-blue to black above with oblong, black spots, and is silvery white below. The freshwater variety is very dark overall. Chinook Salmon are very highly prized game fish in northern California. The Chinook inhabits freshwater streams in California, Washington, Oregon, and Idaho (Boschung et al., 391)

Brook Trout (Salvelinus fontinalis)

Brook Trout are a maximum of twenty-one inches and fourteen and a half pounds. The marine coloration is a bluish-green back, becoming silvery on the side with a white belly. The freshwater variety has red or yellowish tint on back and sides and red spots in blue halos on sides. Brook Trout inhabit cool freshwater streams and are found in California, Connecticut, Delaware, Idaho, Maine, Massachusetts, Michigan, Montana, Nevada, New Hampshire, New Jersey, New York, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin, and Wyoming. (Boschung et al., 396)

Brown Trout (Salmo trutta)

Brown Trout may grow to forty inches in length and just over thirty-nine pounds in weight. Brown Trout have an olive back and sides with red or orange spots, often with a halo, and a silvery belly. Brown Trout are moderately desired game fish. Brown Trout inhabit high gradient freshwater streams and are found in Arizona, Arkansas, California, Colorado, Connecticut, Massachusetts, Minnesota, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Mexico, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin, and Wyoming. (Boschung et al., 396)

Coolwater Fish

Pumpkinseed (Lepomis gibbosus)

Pumpkinseeds are dark greenish gold mottled with reddish orange on their backs, have greenish yellow, mottled orange, and blue-green sides, and a yellow-orange belly. They can grow to 10" in length and 1 lb in weight. Pumpkinseeds are found in cool shallow streams, ponds, marshes, and lakes with heavy vegetation. Pumpkinseeds are sought by beginner anglers. They are native to Connecticut, Delaware, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, West Virginia, and Wisconsin. (Boschung et al., 554)

Muskellunge (Esox masquinongy)

The Muskellunge can grow to a length and weight of six feet and one hundred pounds. The back of a Muskellunge is greenish to light brown on the back and sides greenish-gray to silvery with dark spots or diagonal bars and a creamy-white belly. The "Musky" is sought by anglers. Inhabits lakes and reservoirs with heavy vegetation and slow, meandering streams and rivers with heavy plant cover. Muskellunge are native to Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, New Hampshire, New York, Ohio, Pennsylvania, Tennessee, Vermont, Virginia, West Virginia, and Wisconsin. (Boschung et al., 403)

Northern Pike (Esox lucius)

The Northern Pike has a maximum length and weight of 4'4" and 46 1/8 lbs. They are characterized by a dark olive-green to greenish-brown back, lighter sides, and irregular rows of yellow spots and a small gold spot on the exposed edge of it's scales. The Northern Pike is a valued game fish and inhabits lakes, reservoirs, and large streams with low current and heavy vegetation. They are common in Connecticut, Delaware, Illinois, Indiana, Iowa, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Dakota, Vermont, and Wisconsin. (Boschung et al., 402)

Yellow Perch (Perca flavescens)

The largest Yellow Perch grow to 15" and 4 1/4 lbs. The Yellow Perch is brassy-green to golden yellow above with 5-8 dusky bars across it's back almost to the belly. The Yellow Perch is a sport fish and inhabits open streams, lakes, ponds, and reservoirs with clear water and aquatic vegetation. The Yellow Perch is found in Alabama, Connecticut, Delaware, Florida, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New York, North Carolina, North Dakota, Ohio, Pennsylvania, Rhode Island, South Carolina, South Dakota, Vermont, Virginia, West Virginia, and Wisconsin. (Boschung et al., 578)

Walleye (Stizostedion vitreum)

Walleye are up to three feet and five inches in length and twenty-five pounds. Walleye are olive-brown to brassy greenish-yellow above with dusky to black mottling. The belly is whitish with a yellow-green tinge. They are highly sought after game fish. Walleye live in deep waters of large streams, lakes, and reservoirs. Walleye are found in Alabama, Arkansas, Colorado, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, New York, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Vermont, West Virginia, Wisconsin, and Wyoming. (Boschung et al., 585)

Warmwater Fish

Rock Bass (Ambloplites rupestris)

Rock Bass can grow to a length and weight of 13" and 3 5/8 lbs. Rock Bass are characteristically have an olive mottled back with dark saddles and bronze blotches and are lighter below with rows of dusky spots. Despite their small size Rock Bass are a popular game fish. Their habitat is cool, clear, rocky streams and shallow lakes with vegetation or other cover. Illinois, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Minnesota, Missouri, New York, North Dakota, Ohio, Pennsylvania, South Dakota, Tennessee, Vermont, Virginia, West Virginia, and Wisconsin. (Boschung et al., 549)

Black/White Crappie (Pomoxis nigromaculatus/annularis)

Black Crappie (and White) are up to 16" in length and 5 lbs in weight. Their coloration is greenish back and silvery green sides with dark green to black scattered mottling. Black and White Crappie live in quiet warm, clear streams, ponds, lakes, and reservoirs. They are popular game fish. Black and White Crappie are found in Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Vermont, Virginia, West Virginia, and Wisconsin. (Boschung et al., 560)

Smallmouth Bass (Micropterus dolomieui)

Smallmouth Bass can grow to a maximum length and weight of twenty- four inches and twelve pounds. Smallmouth Bass have a dark olive to brown back, greenish yellow sides, and dark mottling in the form of midlateral bars. Smallmouth Bass are very popular game fish. They live in cool, clear streams with moderate flow and in lakes and reservoirs. Smallmouth are found in Arkansas, Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, New York, Ohio, Oklahoma, Pennsylvania, Tennessee, Vermont, West Virginia, and Wisconsin. (Boschung et al., 557)

Sauger (Stizostedion canadense)

Sauger have a maximum length of 28" and weight of 8 3/4 lbs. Sauger are gray to dull brown and brassy to orange on the sides with dark markings and a whitish belly. The Sauger is an important game fish. Their habitat is dingy waters of large creeks with moderate to swift currents, lakes, and reservoirs. Alabama, Arkansas, Colorado, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, New

York, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Vermont, Virginia, West Virginia, Wisconsin, and Wyoming. (Boschung et al., 584)

Golden Shiner (Notemigonus crysoleucas)

Golden shiners are up to 12" in length. Golden shiners have a golden to olive back, light olive sides with silvery reflections, and a silvery-yellow belly. Goldens inhabit clear, quiet streams, lakes, ponds, and swamps over mud, sand, or rocks. They are native from the East United States west to Montana, Wyoming, Colorado, Nebraska, and Texas . (Boschung et al., 431)

Gizzard Shad (Dorosoma cepedianum)

The Gizzard Shad can grow to sixteen inches in length. They are dark blue or gray, have silvery sides, and a white belly. Gizzard Shad inhabit freshwater in large rivers, reservoirs, lakes, and estuaries. Gizzard Shad can be found in Alabama, Arkansas, Colorado, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Montana, Nebraska, New Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Vermont, Virginia, West Virginia, and Wisconsin. (Boschung et al., 383)

White Bass (Morone chrysops)

White Bass grow to a maximum of 18" in length and 5 1/4 lbs in weight. They are black-olive to silvery-gray in color and have silvery to white sides with 6-9 dark narrow strips. White Bass are important game fish. The White Bass are found in large streams, lakes, and reservoirs in moderately clear water. White Bass can be found in Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New Mexico, New York, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Vermont, West Virginia, and Wisconsin. (Boschung et al., 534)

Largemouth Bass (Micropterus salmoides)

Largemouth Bass are up to 3'2" in length and 22 1/4 lbs in weight at maximum growth. Largemouth are characterized by an olive to dark green mottled back and greenish yellow sides with a midlateral stripe. They are highly valued as a sport fish. Largemouth Bass inhabit quiet, clear streams, ponds, lakes, and reservoirs. They can be found in Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, West Virginia, and Wisconsin. (Boschung et al., 559)

Bluegill (Lepomis macrochirus)

Bluegill reach a maximum length and weight of twelve inches and four and three quarters pounds. They are dark olive-green in color, have lighter sides with brassy reflections or dusky bars and have white bellies. They are the most popular game fish in the United States. Bluegill inhabit clear, warm pools or streams, lakes, ponds, sloughs, and reservoirs, usually in shallow water with vegetation. Bluegill can be found in Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Vermont, Virginia, West Virginia, and Wisconsin. (Boschung et al., 555)

Rough Fish

White Sucker (Catostomus commersoni)

White Suckers can grow to 24" in length. They are dusky-olive and have greenish-yellow sides with a brassy luster. The White Sucker lives in cool, clear streams and lakes. The White Sucker is native to Arkansas, Colorado, Connecticut, Delaware, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New Mexico, New York, North Dakota, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Dakota, Tennessee, Vermont, Virginia, West Virginia, Wisconsin, and Wyoming. (Boschung et al., 459)

Green Sunfish (Lepomis cyanellus)

Green Sunfish are up to 10" long and weigh as much as 2 1/4 lbs. Green Sunfish are yellowish olive their sides sometimes have dusky bars and their belly is pale olive. They inhabit clear to turbid waters with low current including small streams, swamps, and ponds. Alabama, Arkansas, Colorado, Connecticut, Delaware, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Virginia, West Virginia, Wisconsin, and Wyoming. (Boschung et al., 553)

Smallmouth Buffalo (Ictiohus bubalus)

The Smallmouth can grow to a length of 3' and a weight of 51 lbs. They are dark-olive to gray with grayish to bronze sides. The Smallmouth Buffalo is found in clear to slightly turbid waters with moderate current and in lakes and reservoirs. It is native to Alabama, Arkansas, Colorado, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Minnesota, Mississippi, Missouri, Montana, Nebraska, New Mexico, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, Texas, and West Virginia. (Boschung et al., 462)

Flathead Catfish (Pylodictis olivaris)

The Flathead Catfish reach a maximum length of 4'5" and weight of 91 1/4 lbs. They are olive-yellow to light brown with dark mottling. The Flathead is a good sport fish and inhabits large creeks, rivers, and reservoirs usually near natural debris. The Flathead is native to Alabama, Arkansas, Colorado, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Minnesota, Mississippi, Missouri, Nebraska, New Mexico, New York, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, West Virginia, and Wisconsin (Boschung et al., 475)

Freshwater Drum (Aplodinotus grunniens)

The Freshwater Drum has a maximum length of thirty-five inches and weight of just over fifty-four pounds. They are silvery-bluish above, silvery on the sides, and whitish on the bottom. The Freshwater Drum is widely fished for sport and lives in small to large rivers with slow to moderate current and lakes and reservoirs, usually in deeper water. They are located in Alabama, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Virginia, West Virginia, and Wisconsin. (Boschung et al., 616)

Carp (Cyprinus carpio)

The maximum length and weight of a Carp are 30" and 60 lbs. They are dark olive on the back, have lighter sides, and are yellowish below. Carp are a mildly popular game fish and inhabit clear to turbid waters in sloughs, streams, lakes, ponds, and reservoirs. They are found mainly in bodies of water with aquatic cover and are most common in warm water. Carp range throughout the United States except for Maine. (Boschung et al., 412)

Brown Bullhead (Ictalurus nebulosus)

Brown Bullheads reach a length of 19" and a weight of 5 1/2 lbs. They have an olive to black back, lighter sides mottled with brownish blotches, and a whitish belly. Brown Bullheads are sought by anglers and found in clear water in deep pools with heavy vegetation. They are native from the Dakotas, Minnesota, Missouri, Arkansas, and Louisiana throughout the East United States. (Boschung et al., 470)

Channel Catfish (Ictalurus punctatus)

Channel Catfish can grow to a maximum of 3'11" in length and 58 lbs in weight. They are blue-gray on the back, have light blue to silvery sides with scattered dark olive to black spots, and a white belly. The Channel Catfish is a very popular sport fish. It lives in rivers and large creeks with slow to moderate current and in ponds, lakes, and reservoirs. Channel Catfish are found in Alabama, Arkansas, Colorado, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, West Virginia, Wisconsin, and Wyoming. (Boschung et al., 470)

REFERENCES

Boschung, Herbert T., Jr., James D. Williams, Daniel W. Gotshall, David K. Caldwell, and Melba C. Caldwell. 1983. The Audubon Society: Field Guide to North American Fishes, Whales & Dolphins. New York: Knopf.

APPENDIX B

GISS EQUILIBRIUM

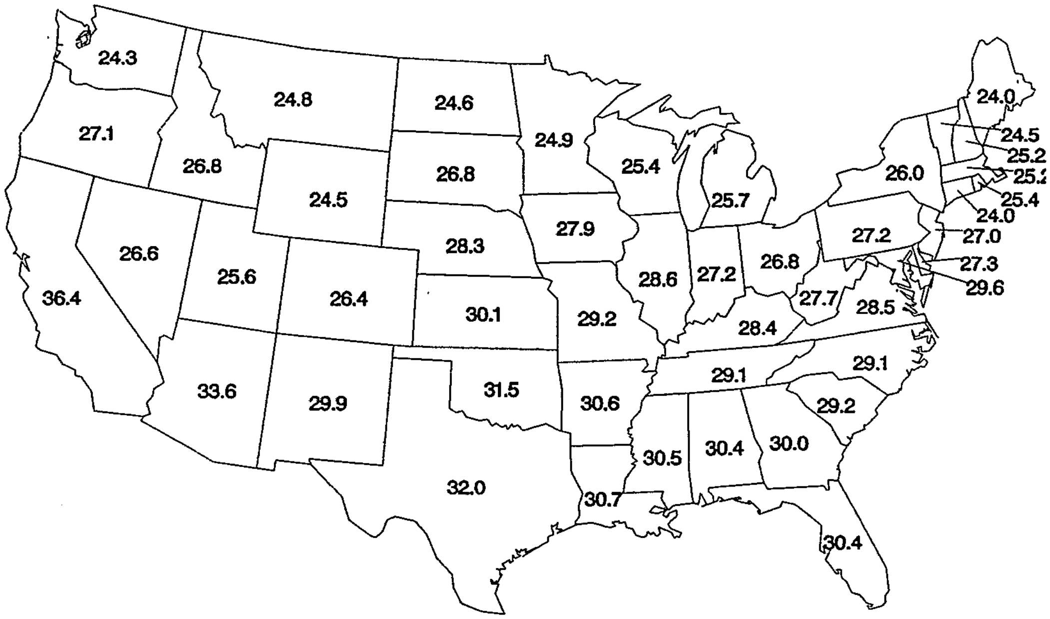
U.S. Maps Showing Increased Temperature and Habitat Changes for Recreational Fish

EXHIBIT B-1

Maximum Weekly Average Temperature at Doubled CO^2

GISS Equilibrium Results
(Scaled to IPCC 92 "Best Estimate" Climate Sensitivity)

Highest Maximum per State



Lowest Maximum per State

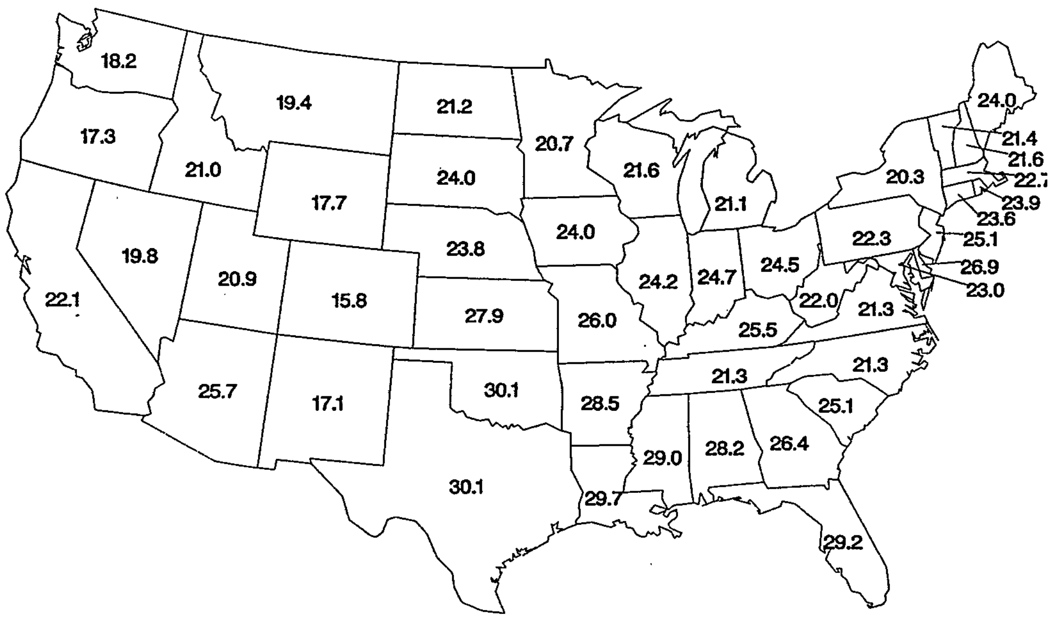


EXHIBIT B-2

Loss of Habitability by Guild

GISS Equilibrium - Doubled CO_2

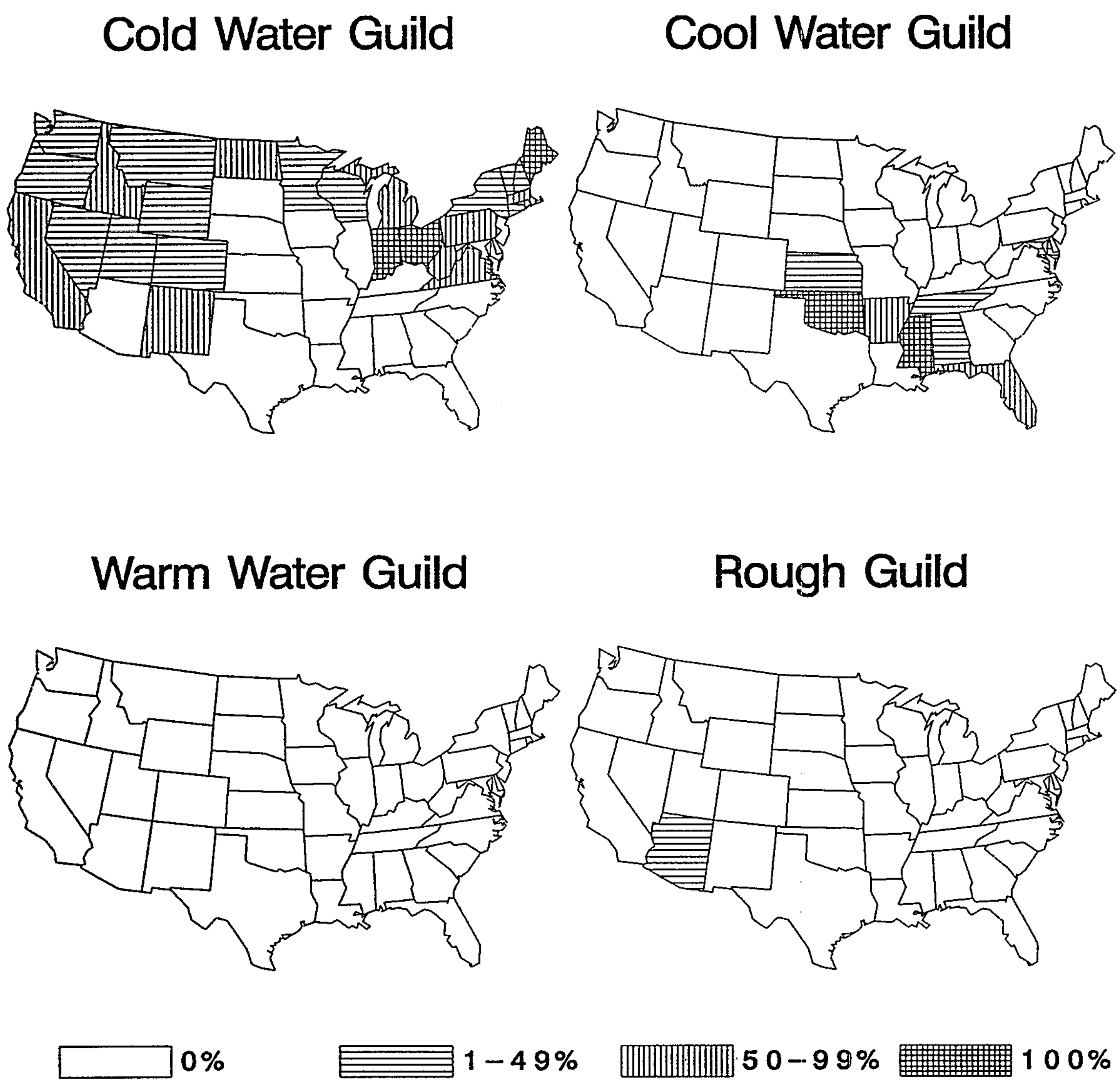


EXHIBIT B-3

Loss of Habitability for Cold Water Species

GISS Equilibrium - Doubled CO_2

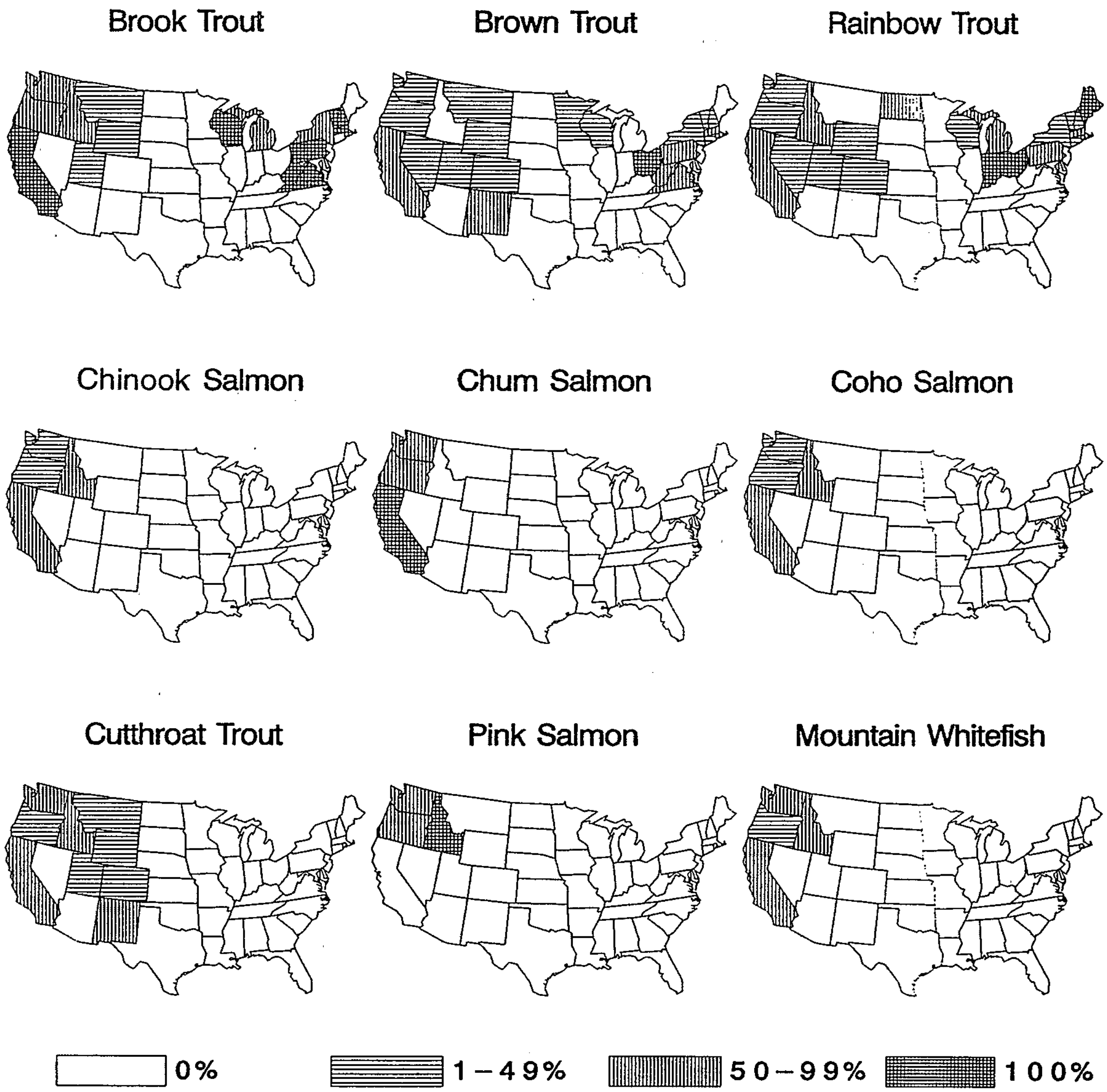


EXHIBIT B-4

Loss of Habitability for Cool Water Species

GISS Equilibrium - Doubled CO_2

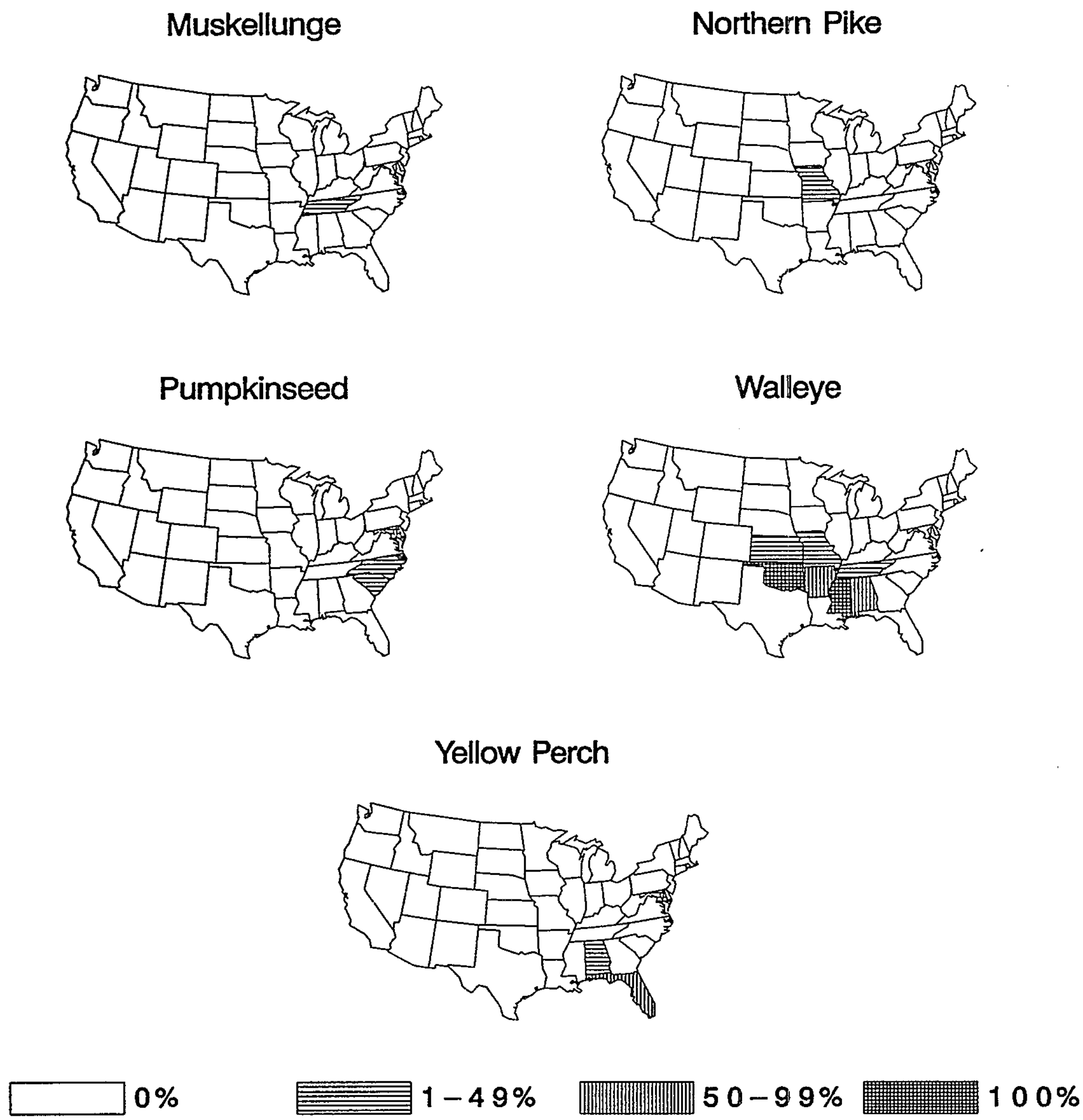


EXHIBIT B-5

Loss of Habitability for Warm Water Species

GISS Equilibrium - Doubled CO_2

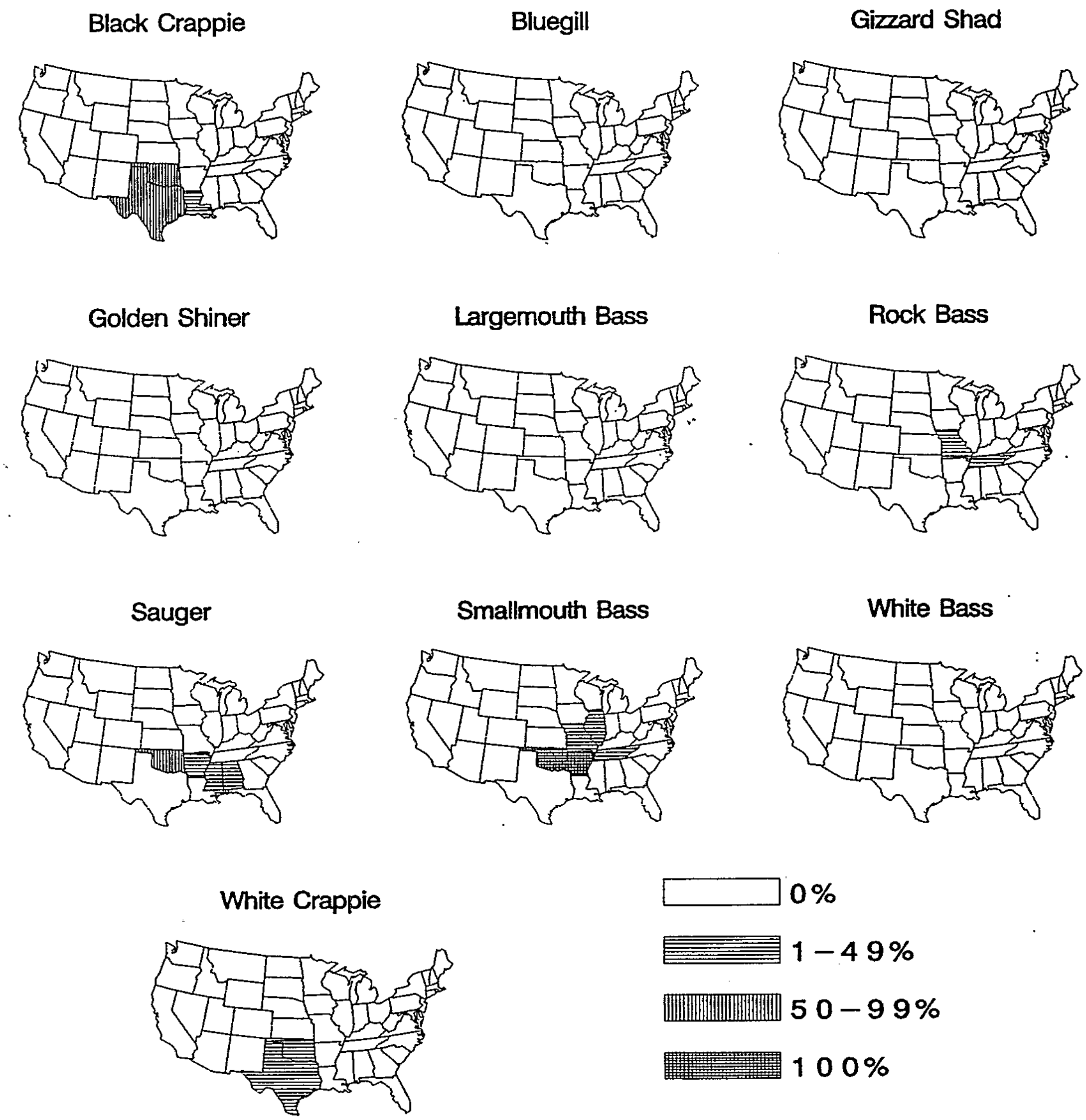
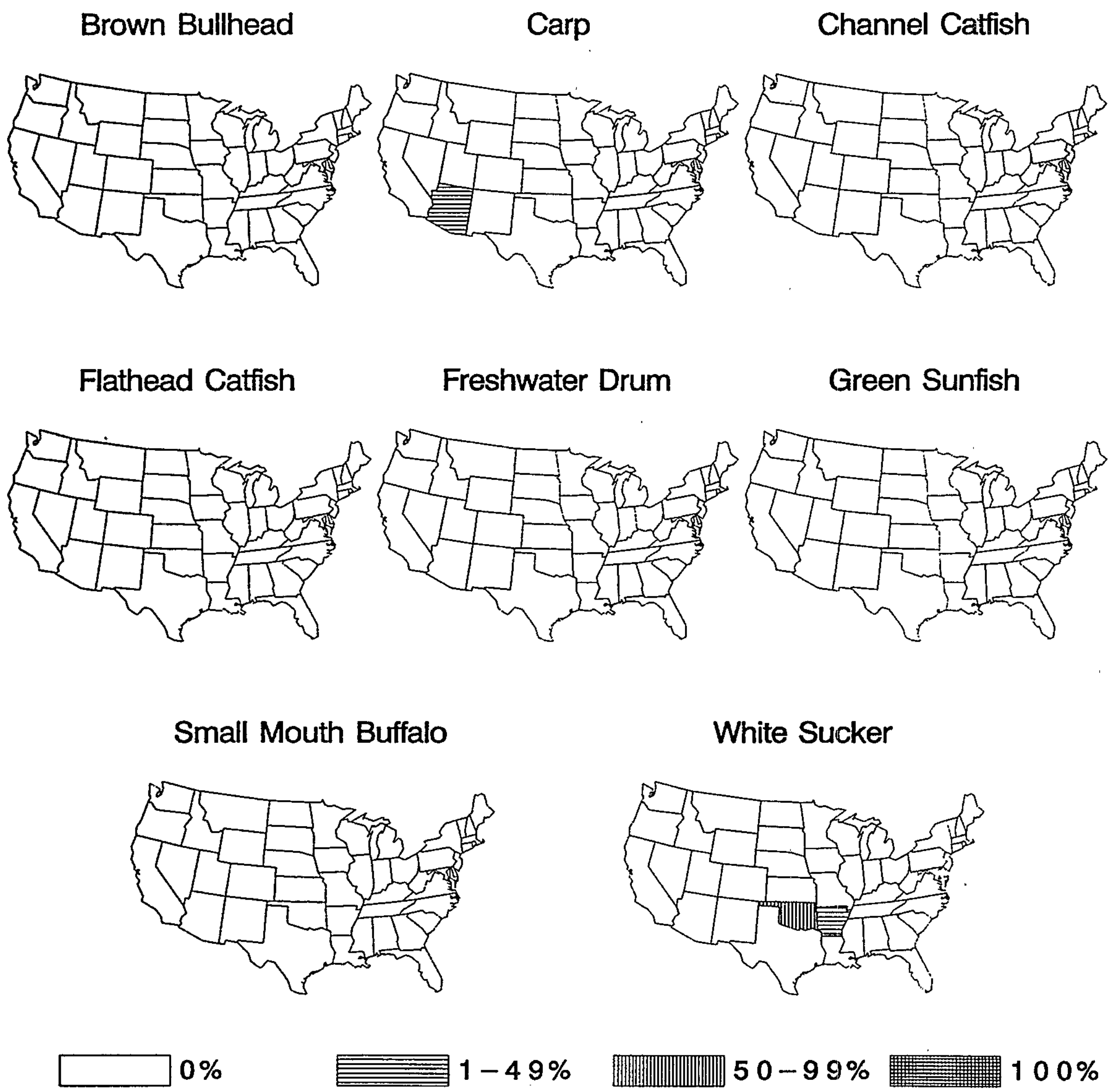


EXHIBIT B-6

Loss of Habitability for Rough Water Species

GISS Equilibrium - Doubled CO_2



APPENDIX C

OSU EQUILIBRIUM

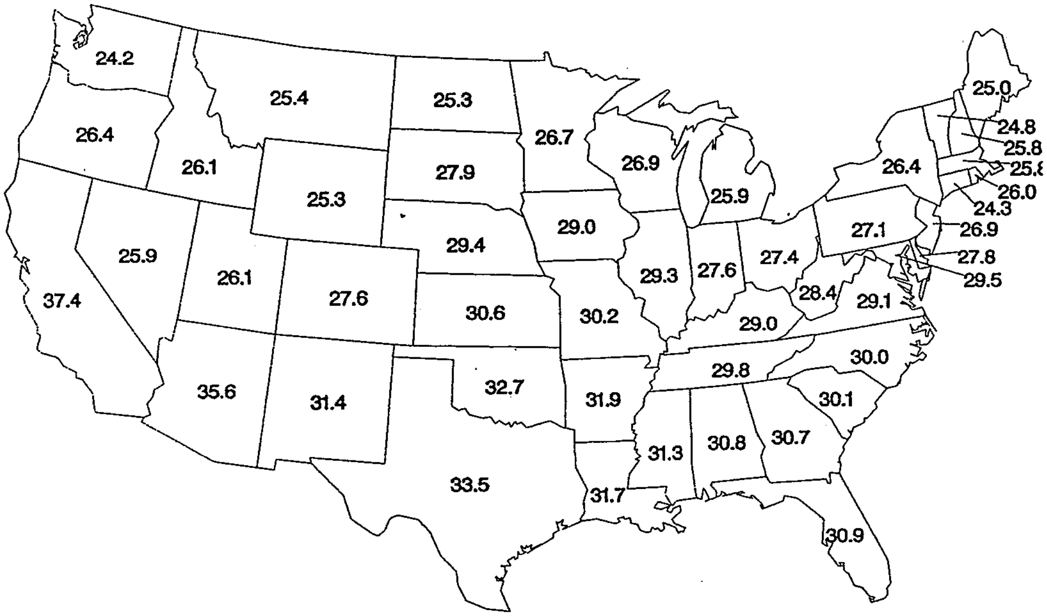
U.S. Maps Showing Increased Temperature and Habitat Changes for Recreational Fish

EXHIBIT C-1

Maximum Weekly Average Temperature at Doubled CO_2

OSU Equilibrium Results
(Scaled to IPCC "Best Estimate" Climate Sensitivity)

Highest Maximum per State



Lowest Maximum per State

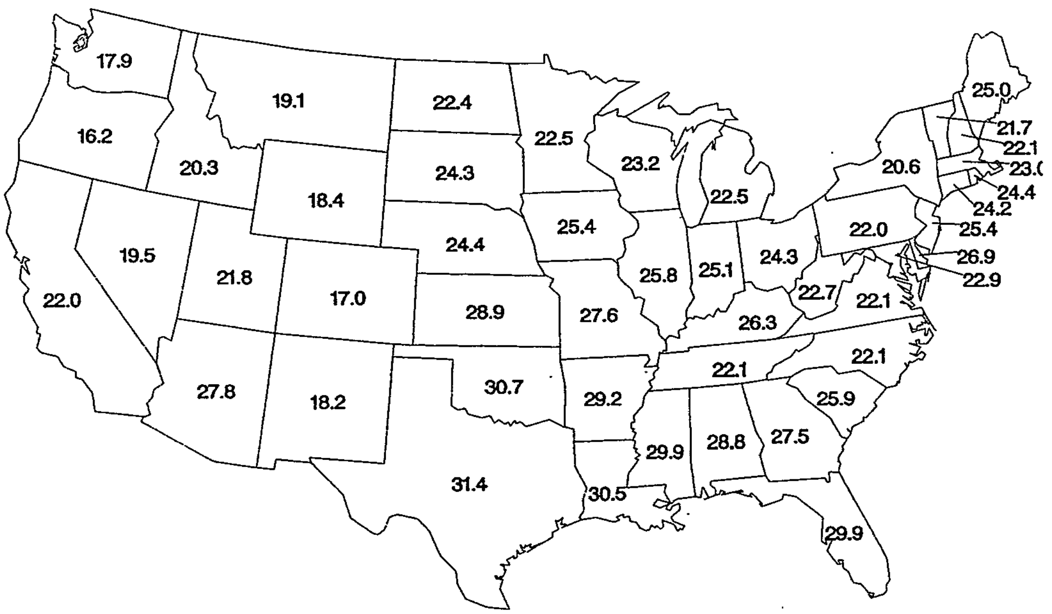


EXHIBIT C-2

Loss of Habitability by Guild

OSU Equilibrium - Doubled CO_2

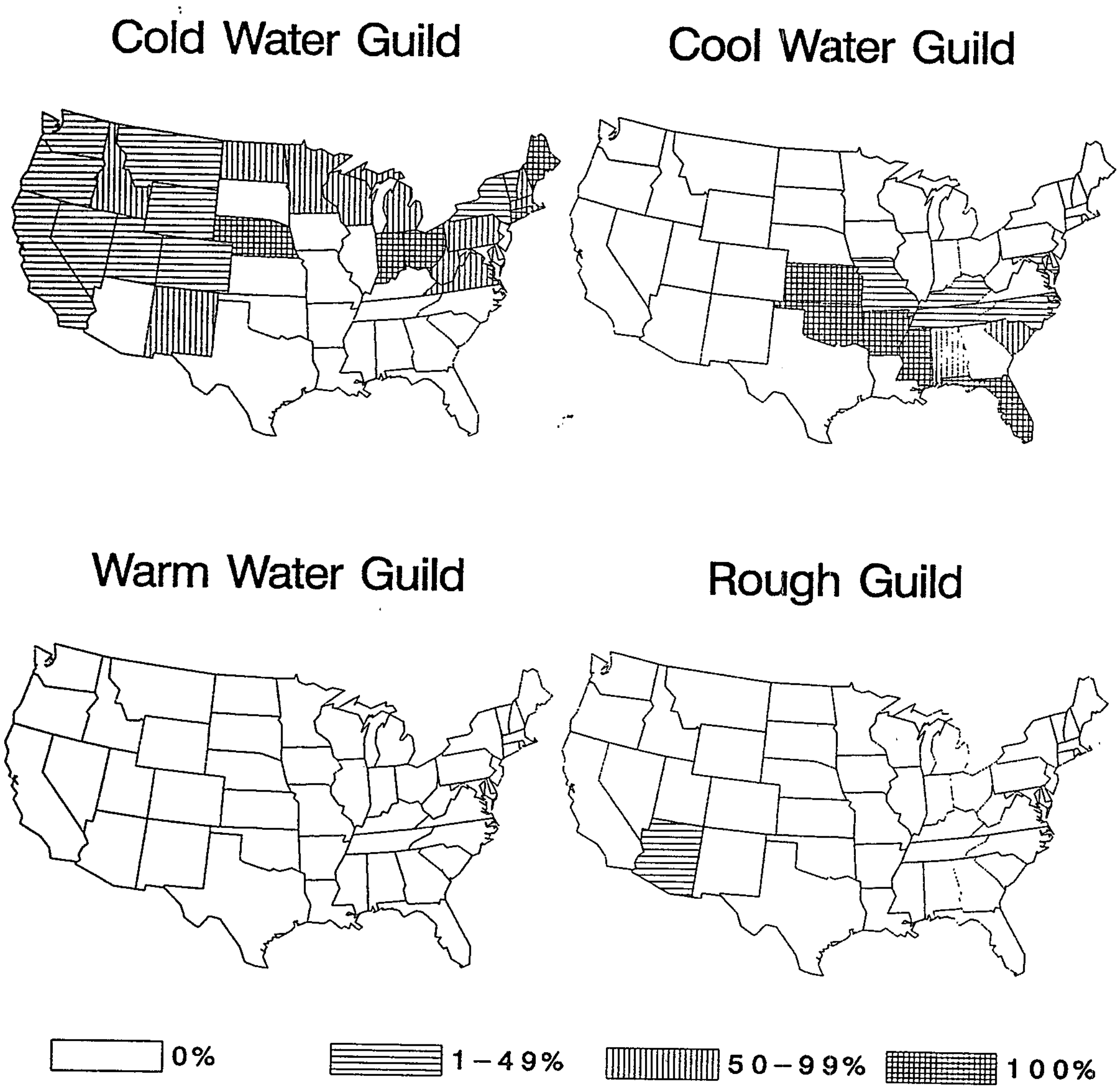


EXHIBIT C-3

Loss of Habitability for Cold Water Species

OSU Equilibrium - Doubled CO_2

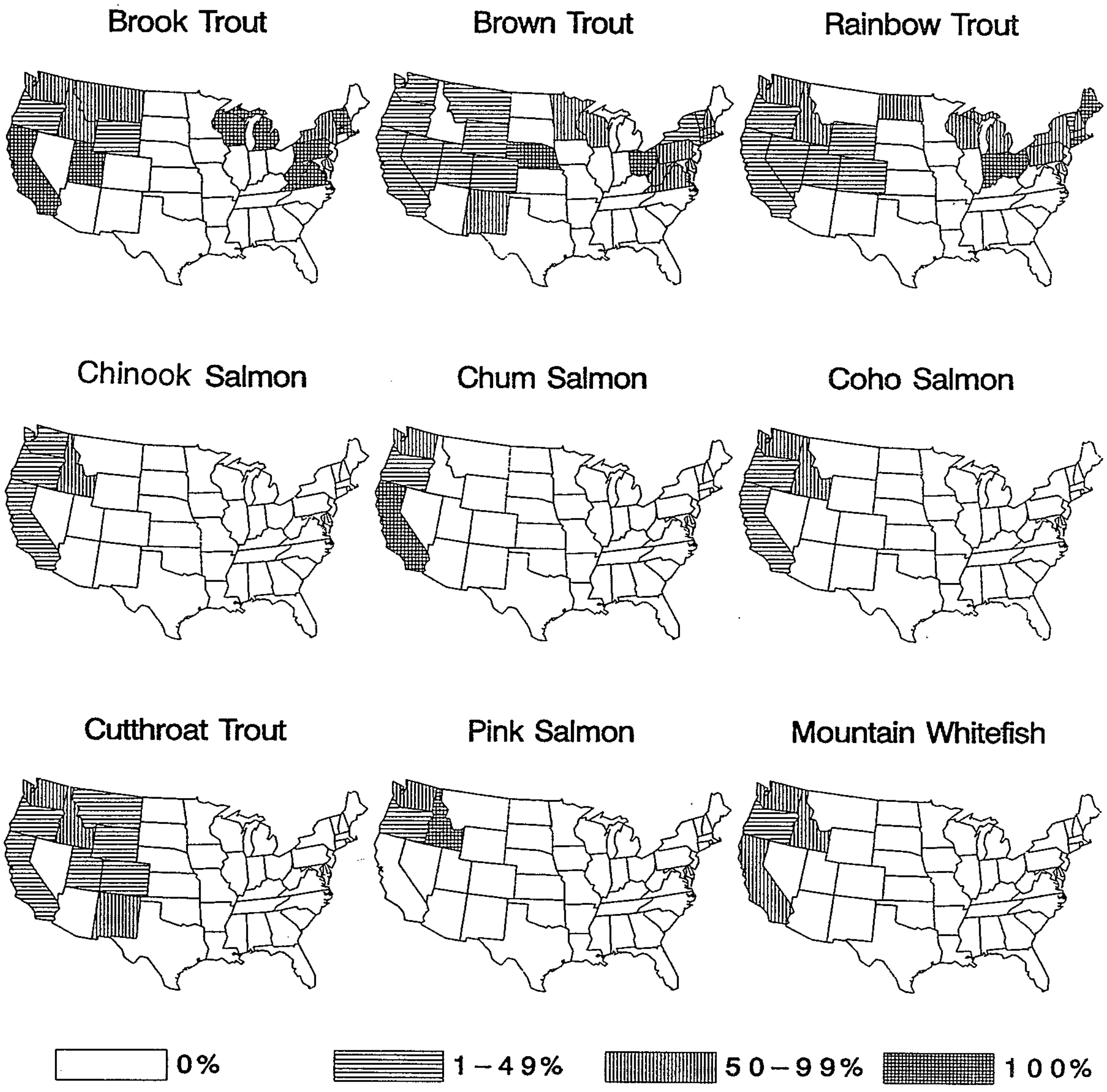


EXHIBIT C-4

Loss of Habitability for Cool Water Species

OSU Equilibrium - Doubled CO_2

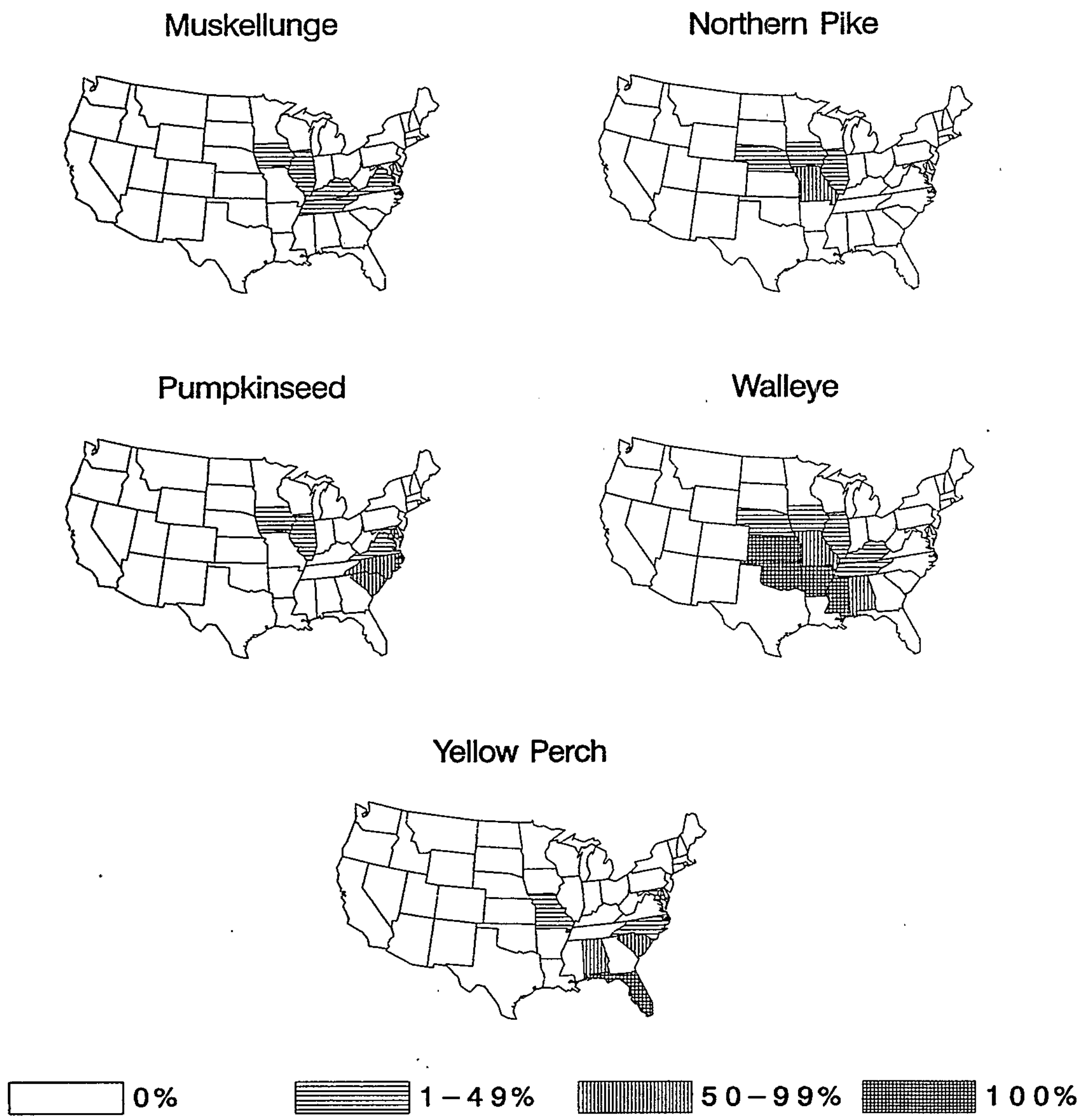


EXHIBIT C-5

Loss of Habitability for Warm Water Species

OSU Equilibrium - Doubled CO_2

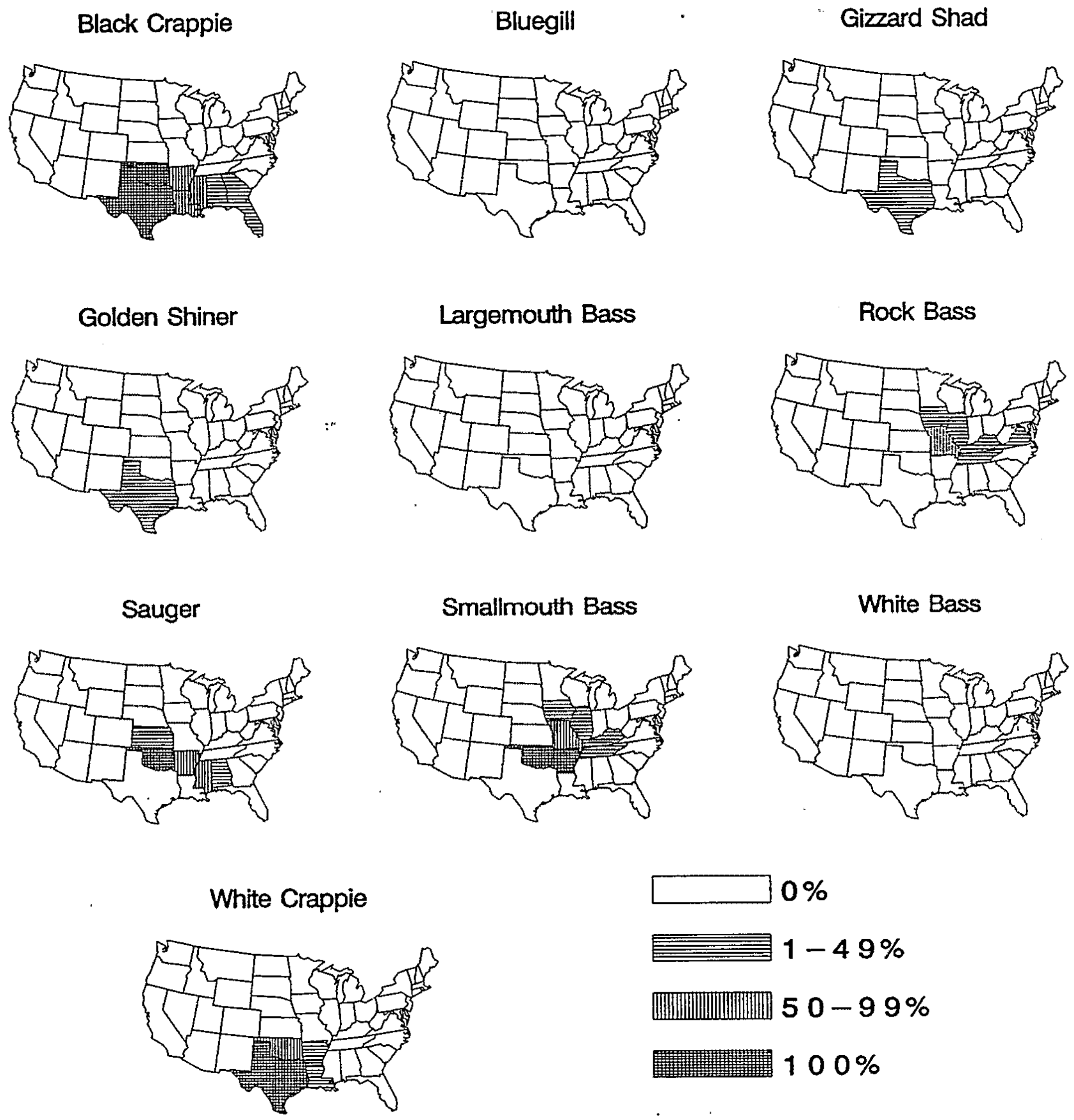
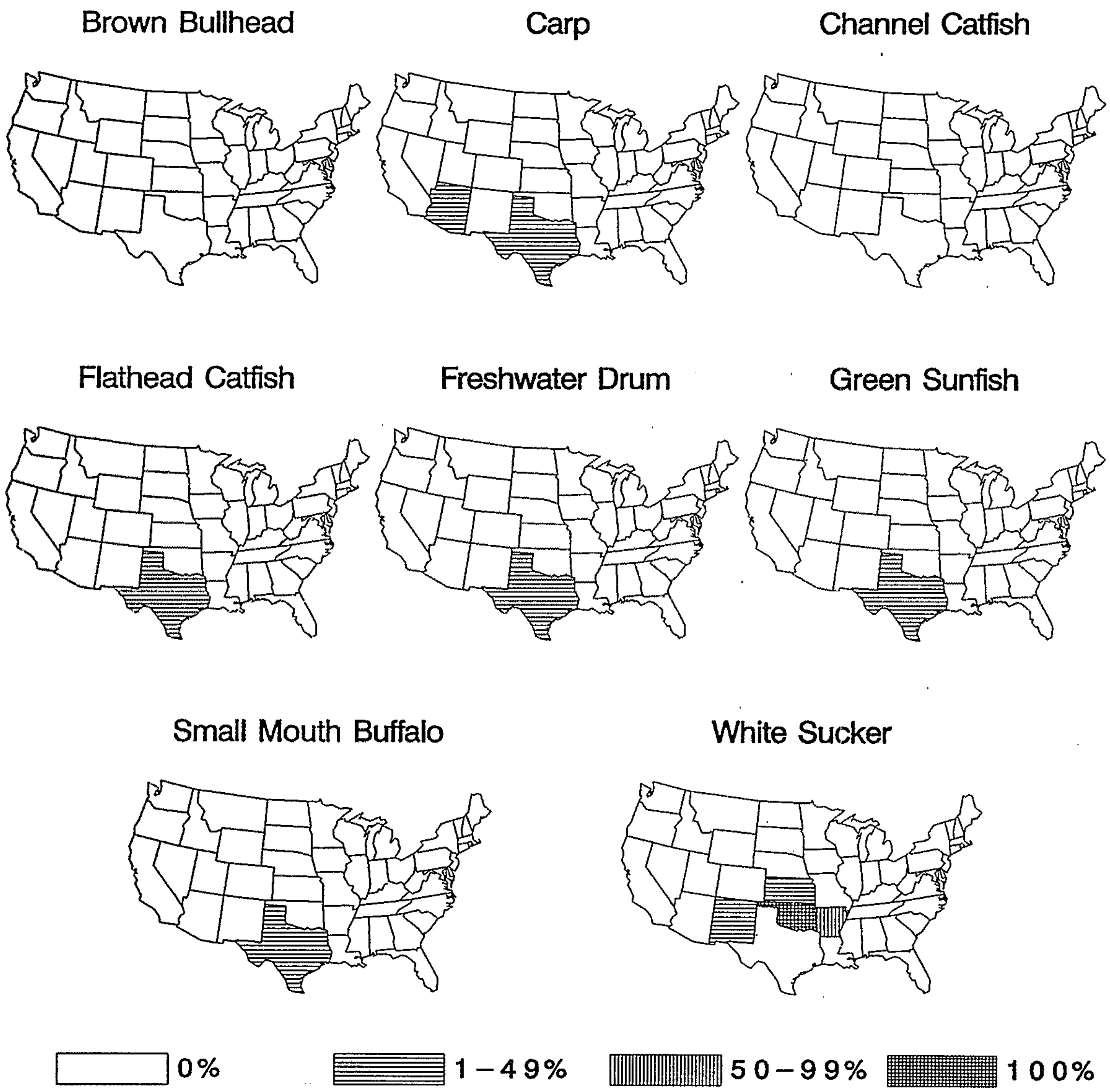


EXHIBIT C-6

Loss of Habitability for Rough Water Species

OSU Equilibrium - Doubled CO_2



APPENDIX D

UKMO EQUILIBRIUM

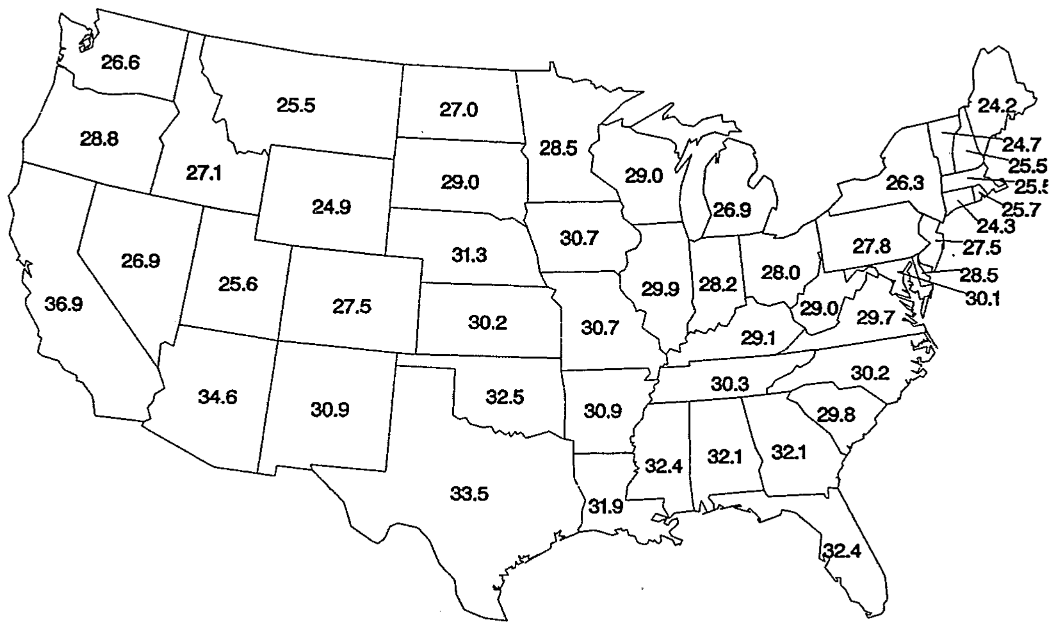
U.S. Maps Showing Increased Temperature and Habitat Changes for Recreational Fish

EXHIBIT D-1

Maximum Weekly Average Temperature at Doubled CO_2

UKM Equilibrium Results (Scaled to IPCC "Best Estimate" Climate Sensitivity)

Highest Maximum per State



Lowest Maximum per State

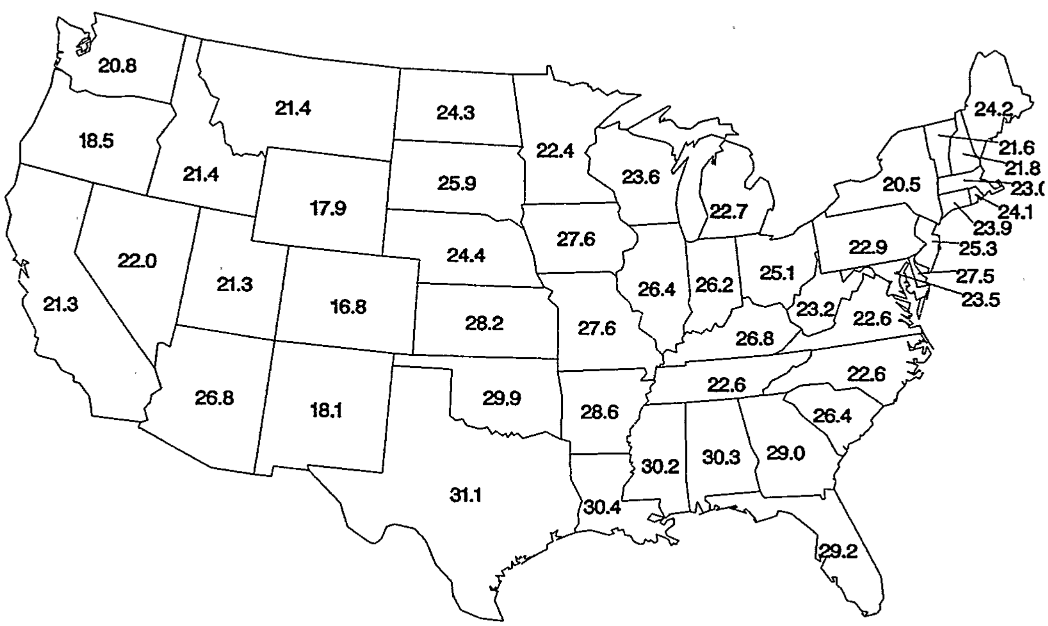


EXHIBIT D-2

Loss of Habitability by Guild

UKM Equilibrium - Doubled CO_2

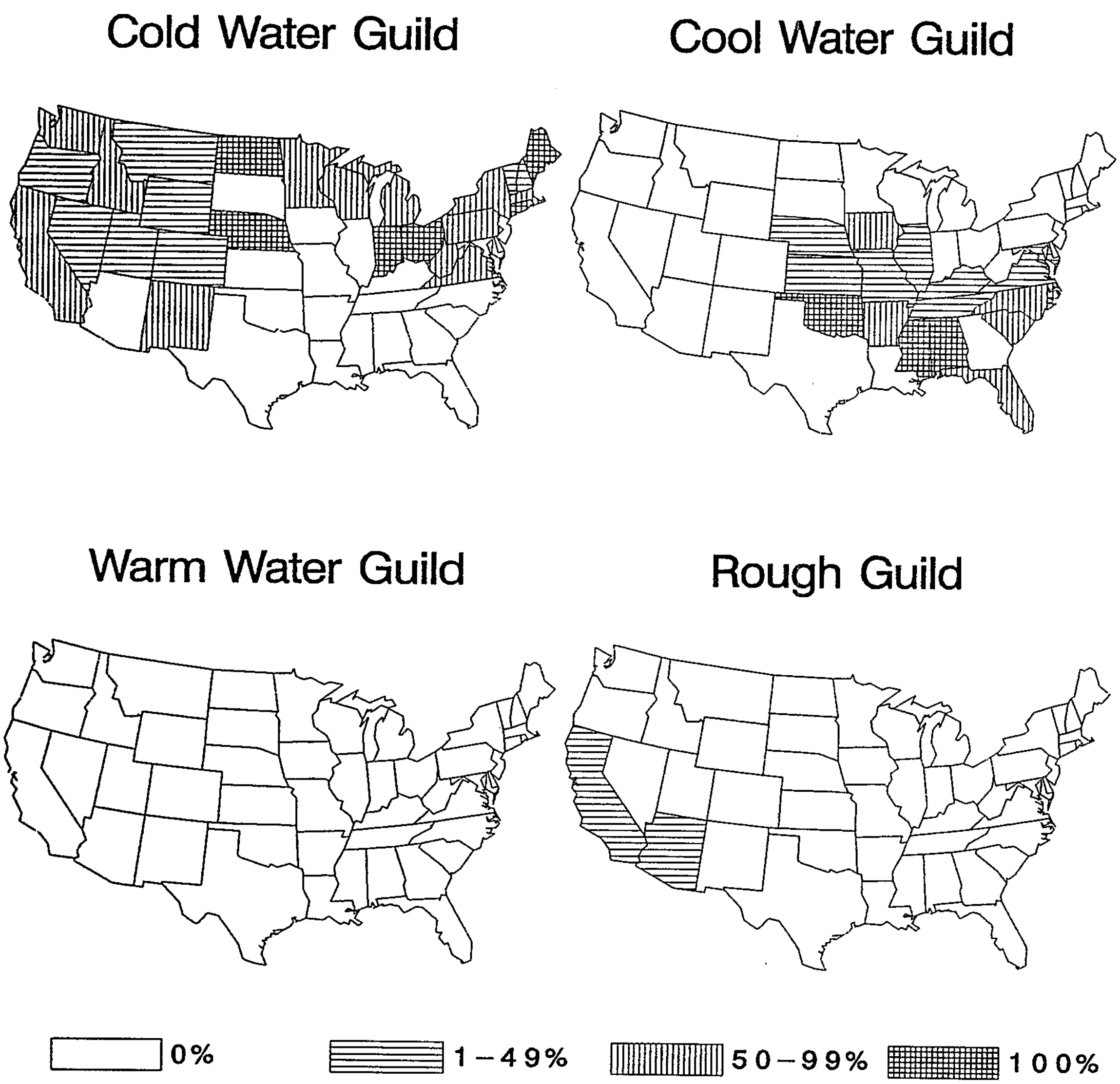


EXHIBIT D-3

Loss of Habitability for Cold Water Species

UKM Equilibrium - Doubled CO_2

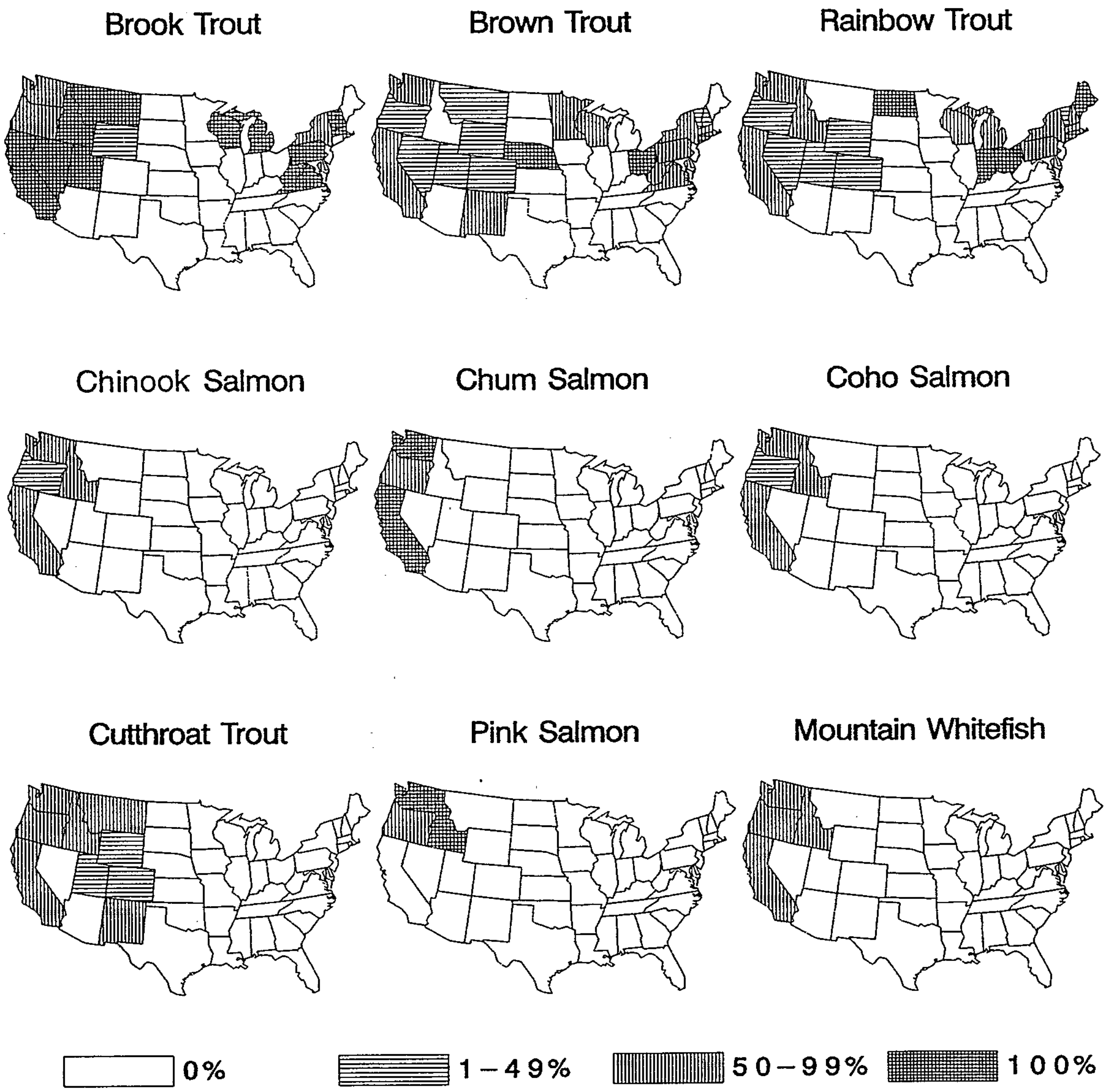


EXHIBIT D-4

Loss of Habitability for Cool Water Species

UKM Equilibrium - Doubled CO_2

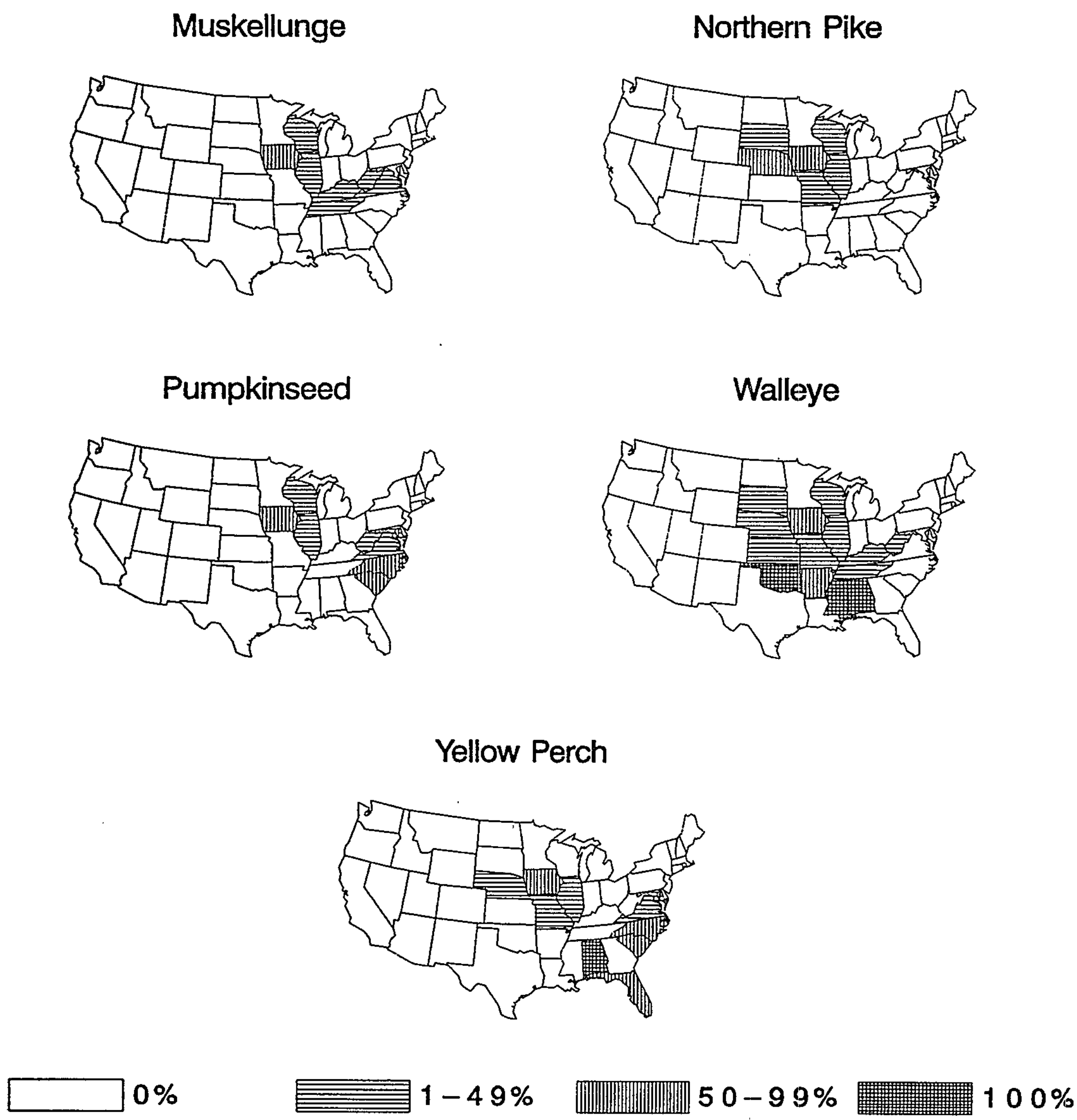


EXHIBIT D-5

Loss of Habitability for Warm Water Species

UKM Equilibrium - Doubled CO_2

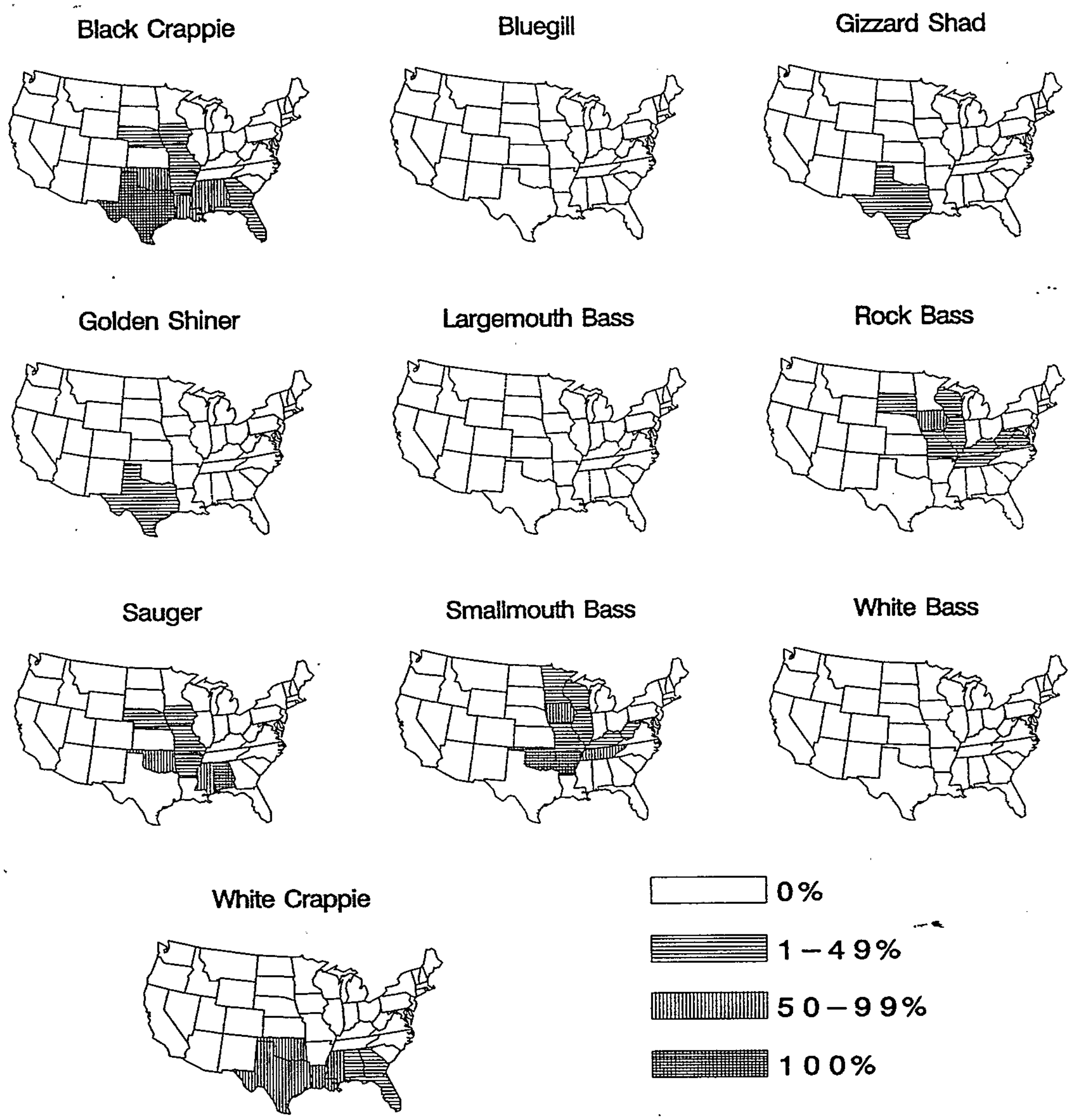
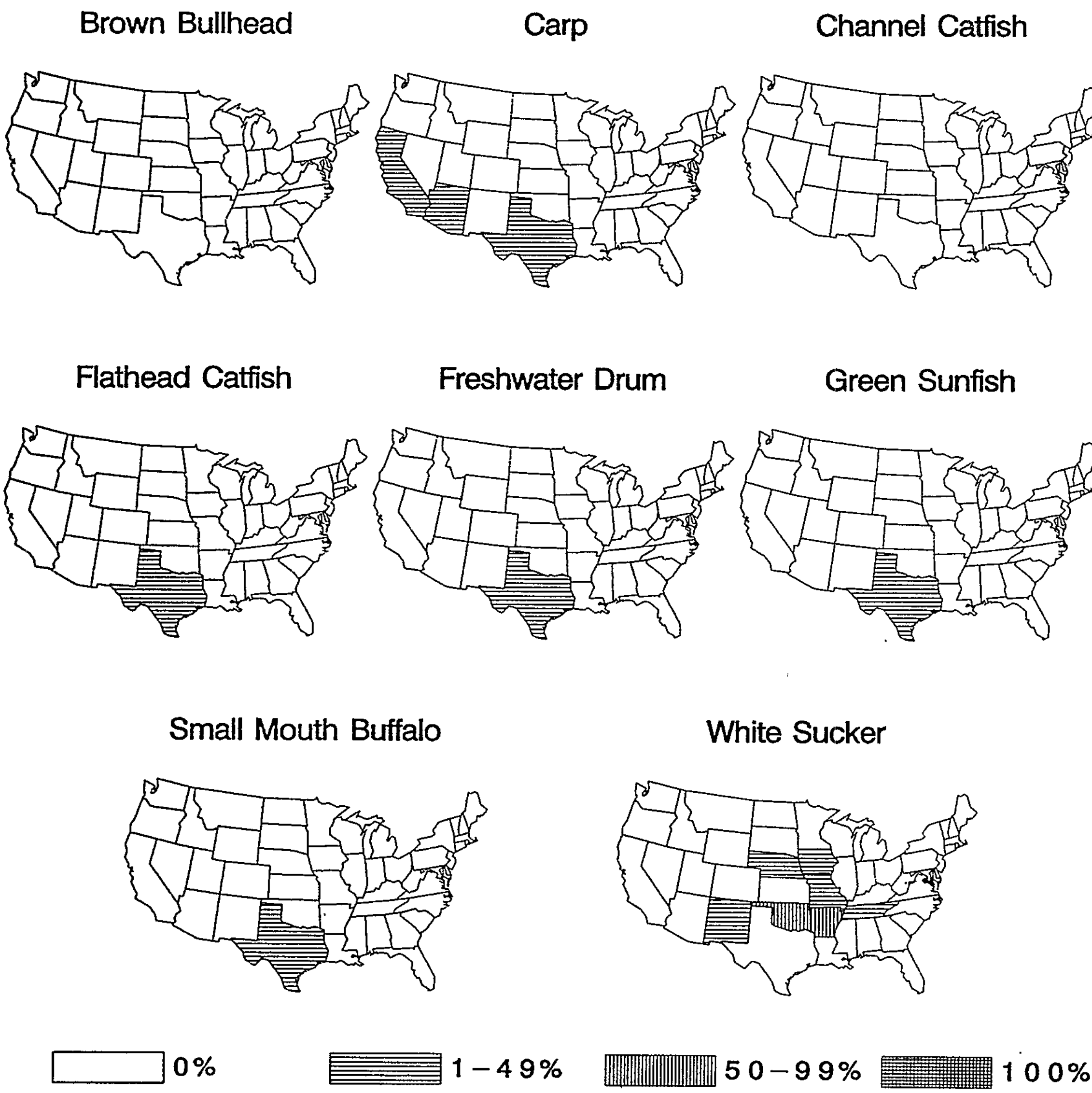


EXHIBIT D-6

Loss of Habitability for Rough Water Species

UKM Equilibrium - Doubled CO_2



APPENDIX E

TRANSIENT GFDL - 2050

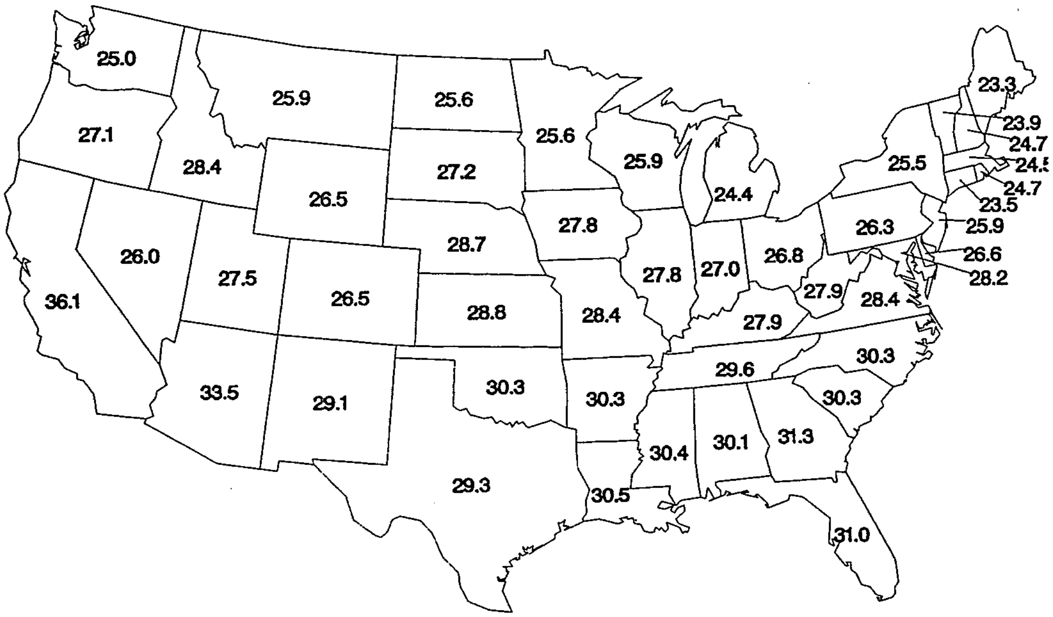
U.S. Maps Showing Increased Temperature and Habitat Changes for Recreational Fish

EXHIBIT E-1

Maximum Weekly Average Temperature at Doubled CO_2

GFDL Transient Results - 2050
(Scaled from "1.16°C Decade")

Highest Maximum per State



Lowest Maximum per State

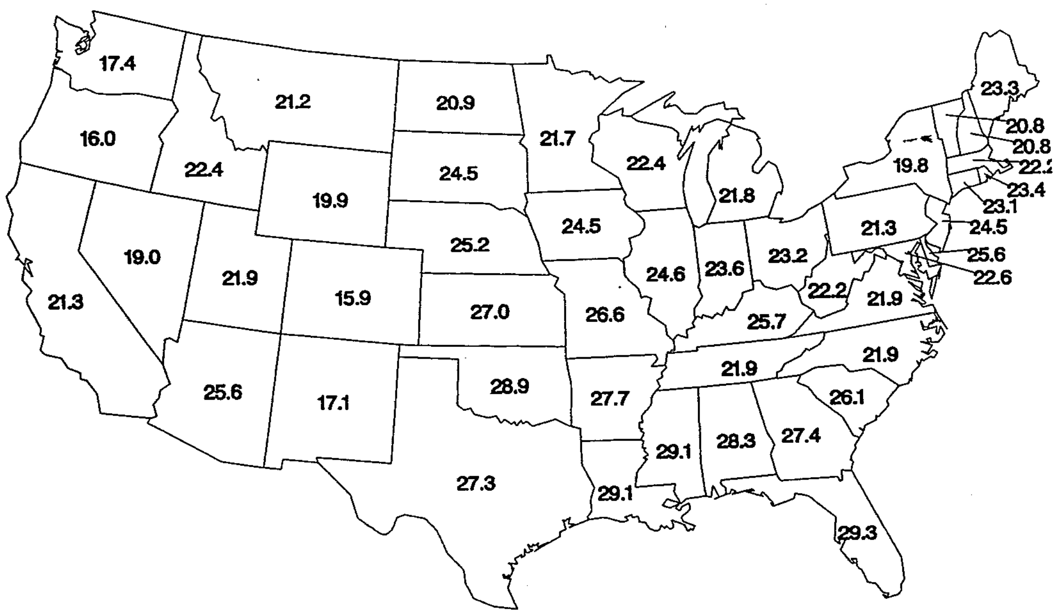


EXHIBIT E-2

Loss of Habitability by Guild

GFDL Transient Results - 2050

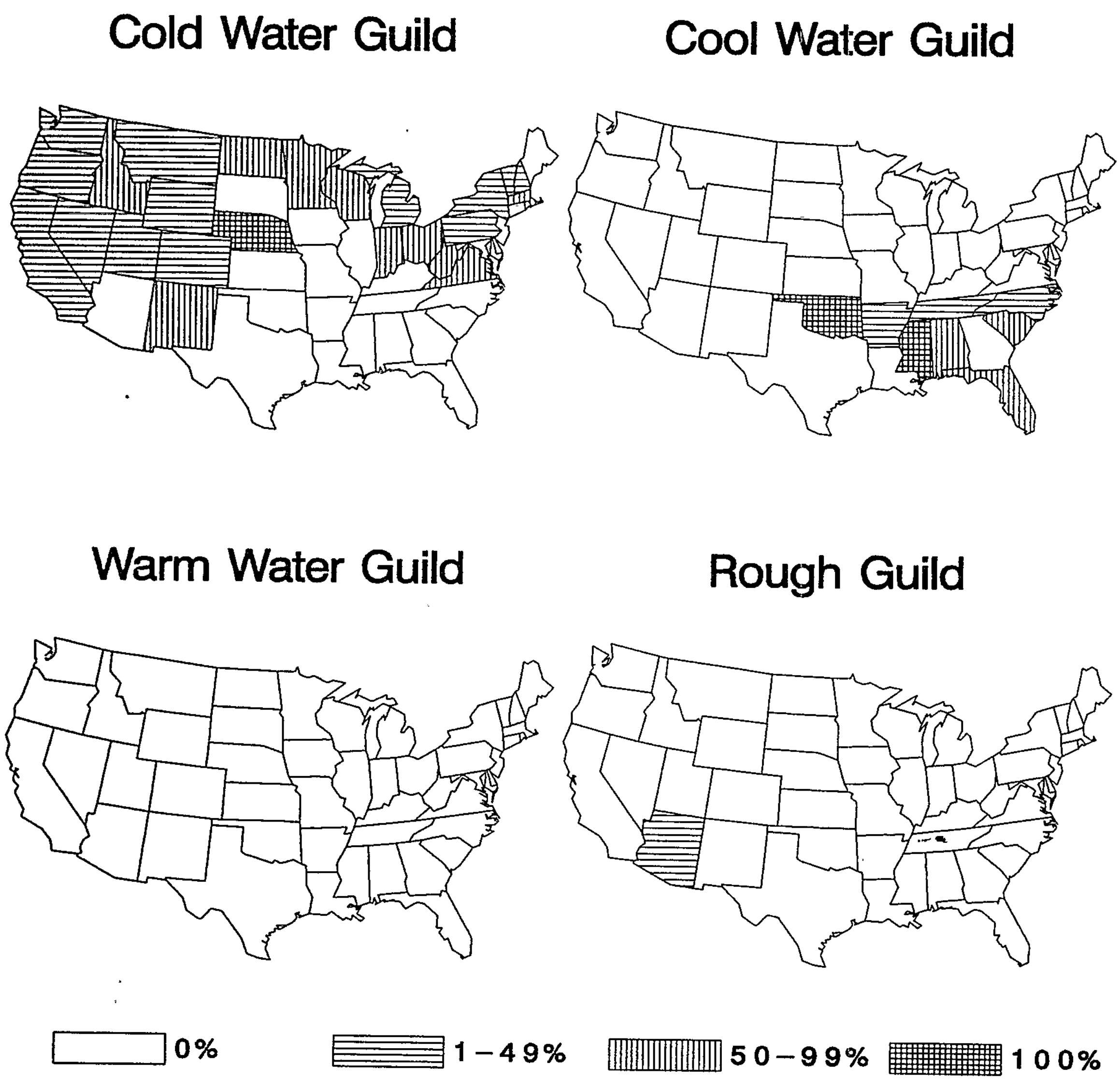


EXHIBIT E-3

Loss of Habitability for Cold Water Species

GFDL Transient Results - 2050

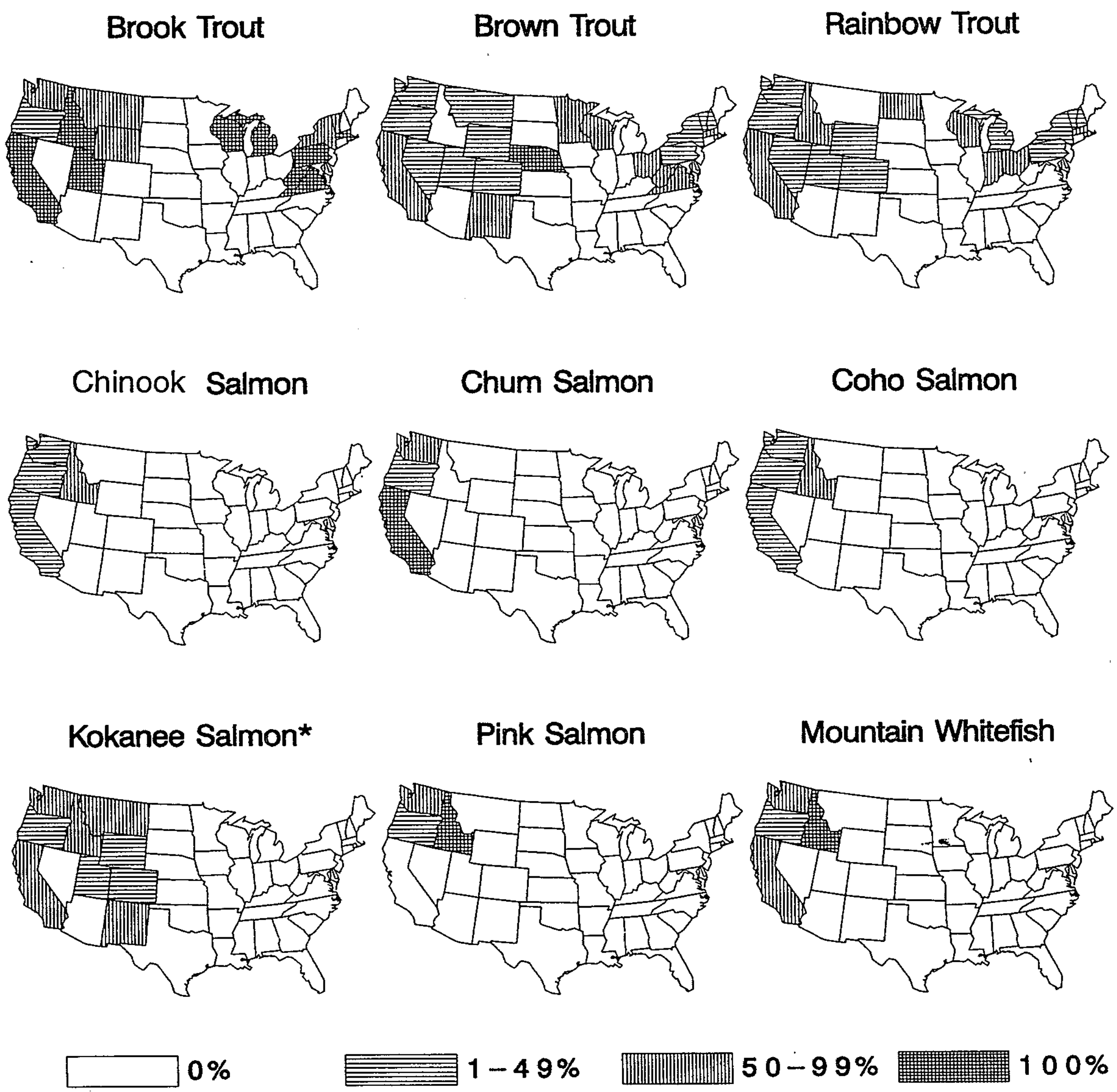


EXHIBIT E-4

Loss of Habitability for Cool Water Species

GFDL Transient Results - 2050

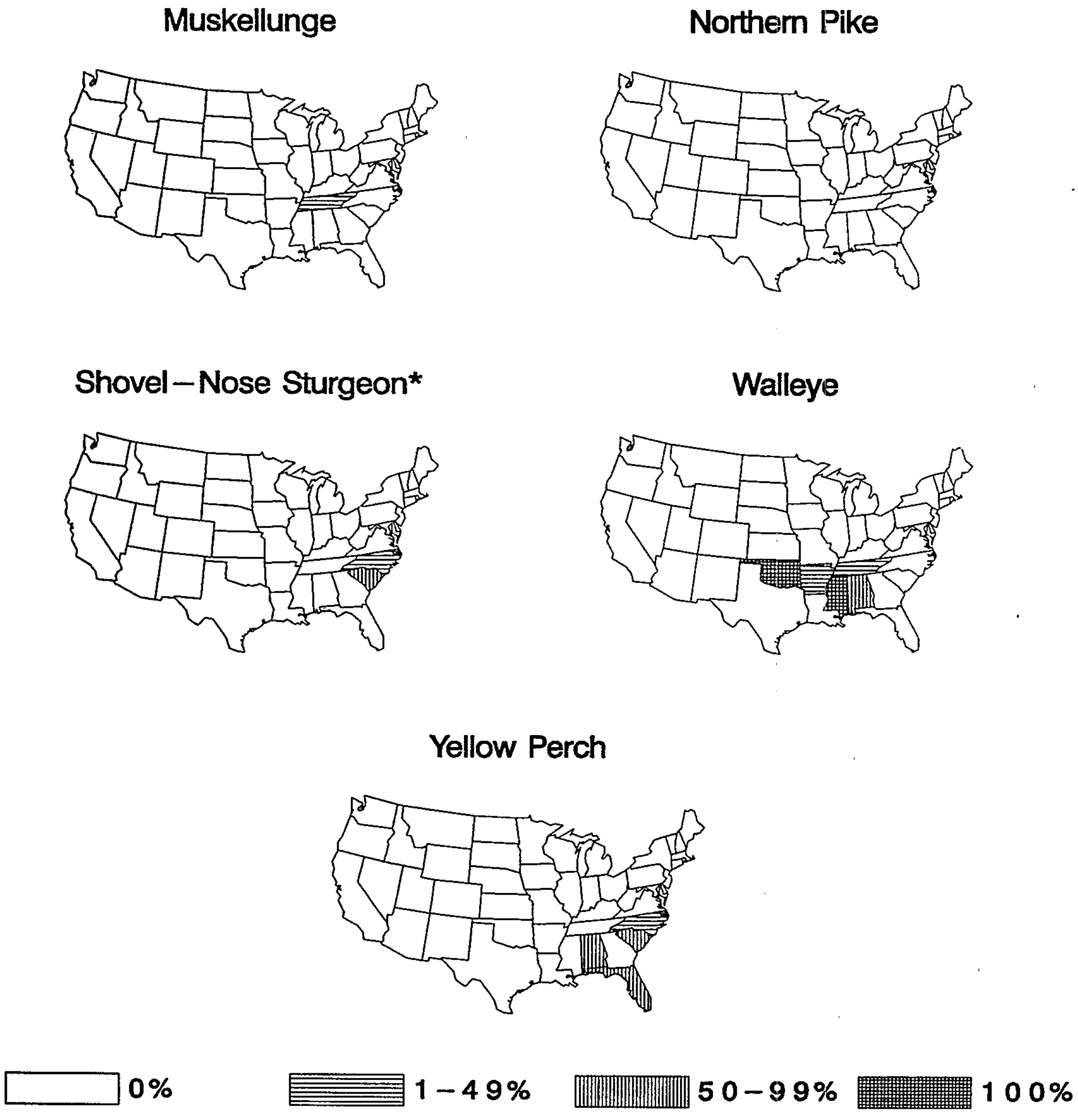


EXHIBIT E-5

Loss of Habitability for Warm Water Species

GFDL Transient Results - 2050

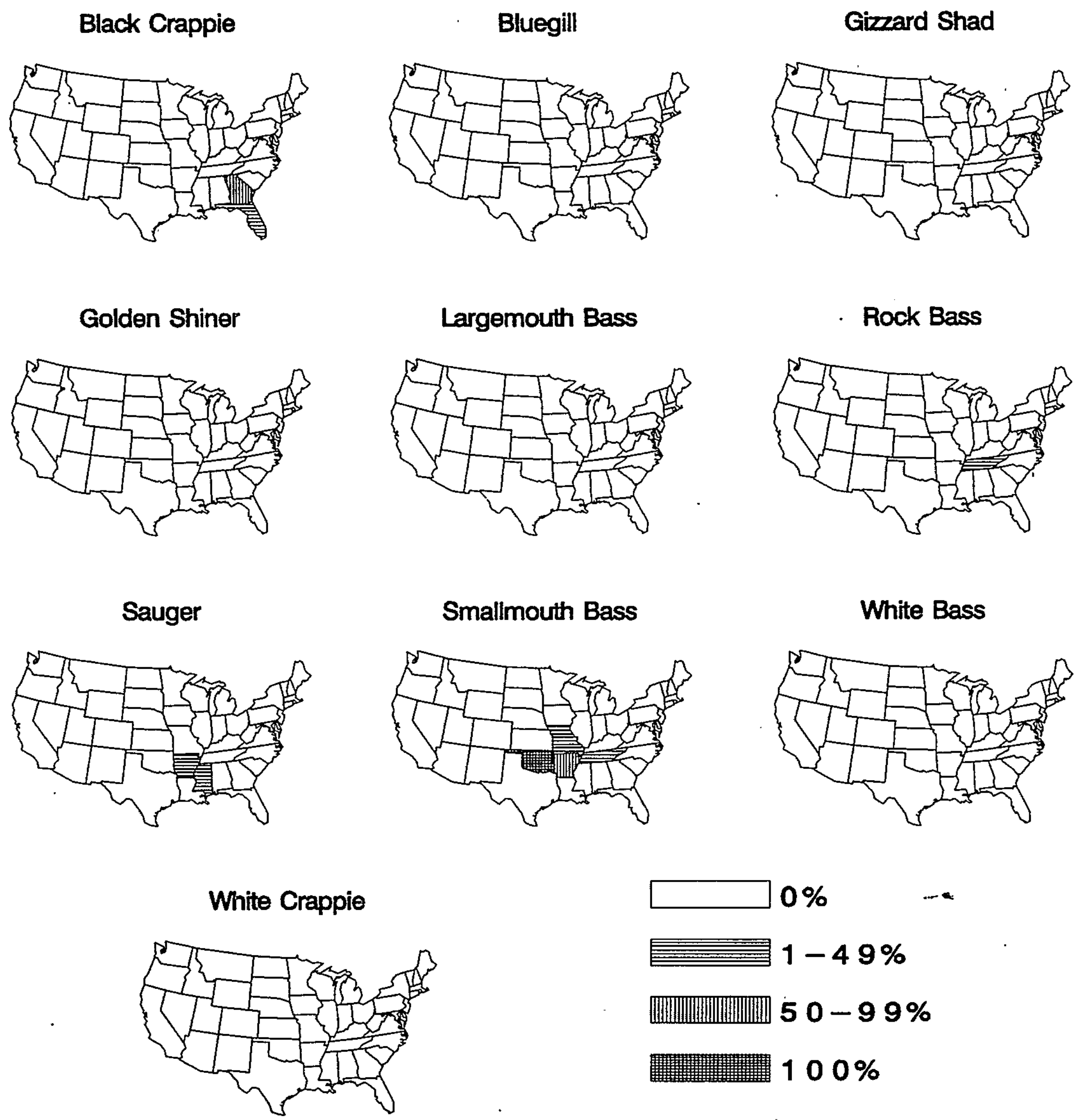
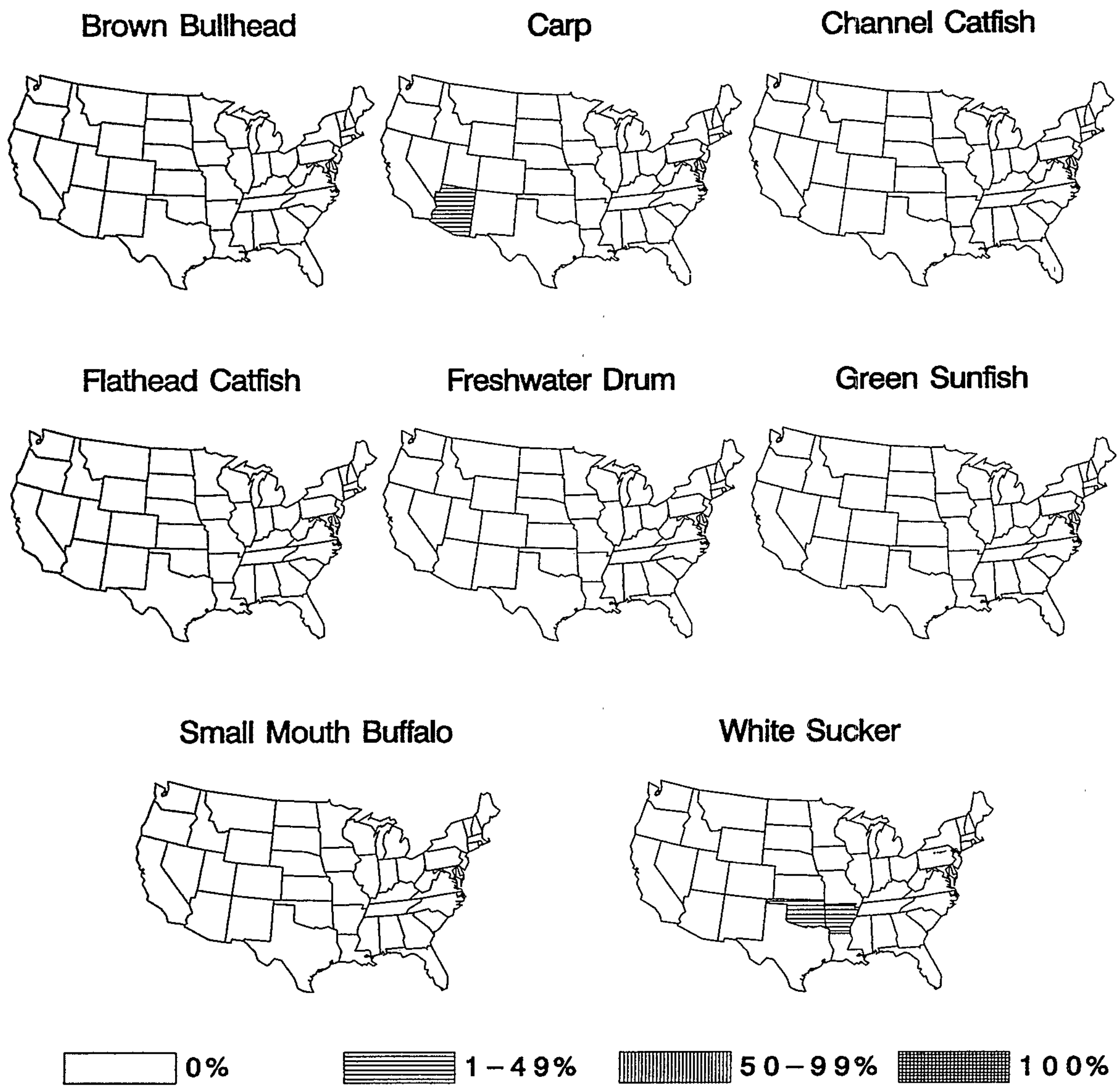


EXHIBIT E-6

Loss of Habitability for Rough Water Species

GFDL Transient Results - 2050



APPENDIX F

TRANSIENT GFDL - 2100

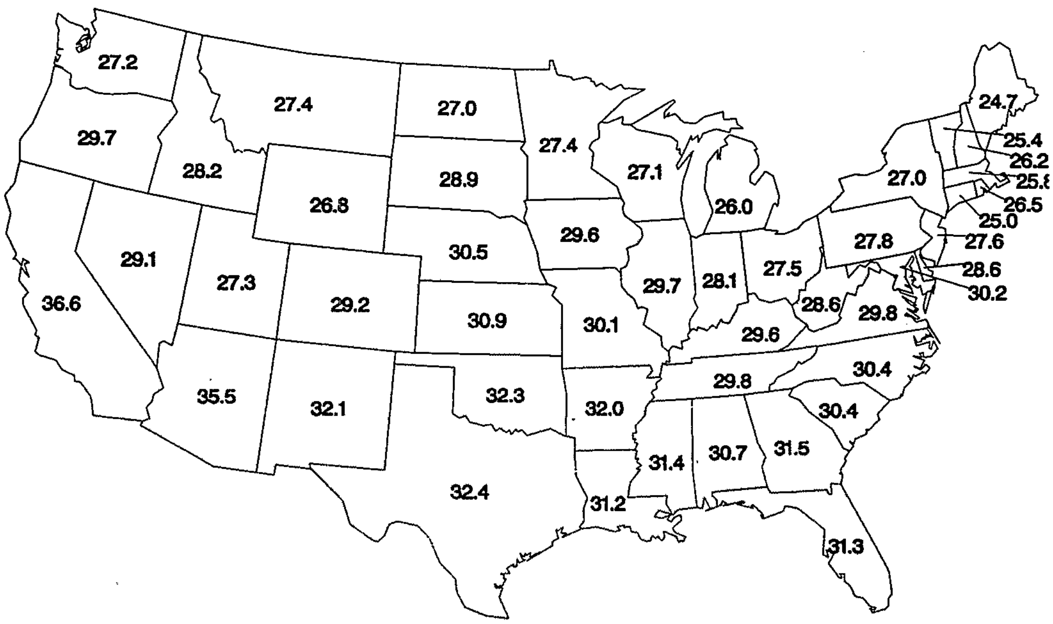
U.S. Maps Showing Increased Temperature and Habitat Changes for Recreational Fish

EXHIBIT F-1

Maximum Weekly Average Temperature at Doubled CO_2

GFDL Transient Results - 2100
(Scaled from "Eighth Decade")

Highest Maximum per State



Lowest Maximum per State

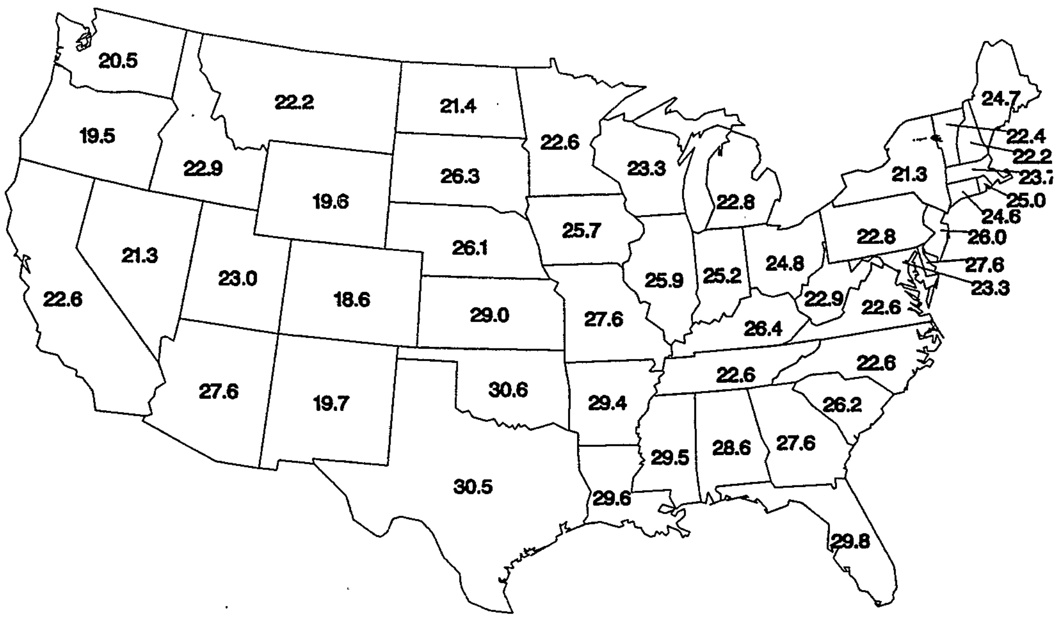


EXHIBIT F-2

Loss of Habitability by Guild

GFDL Transient Results - 2100

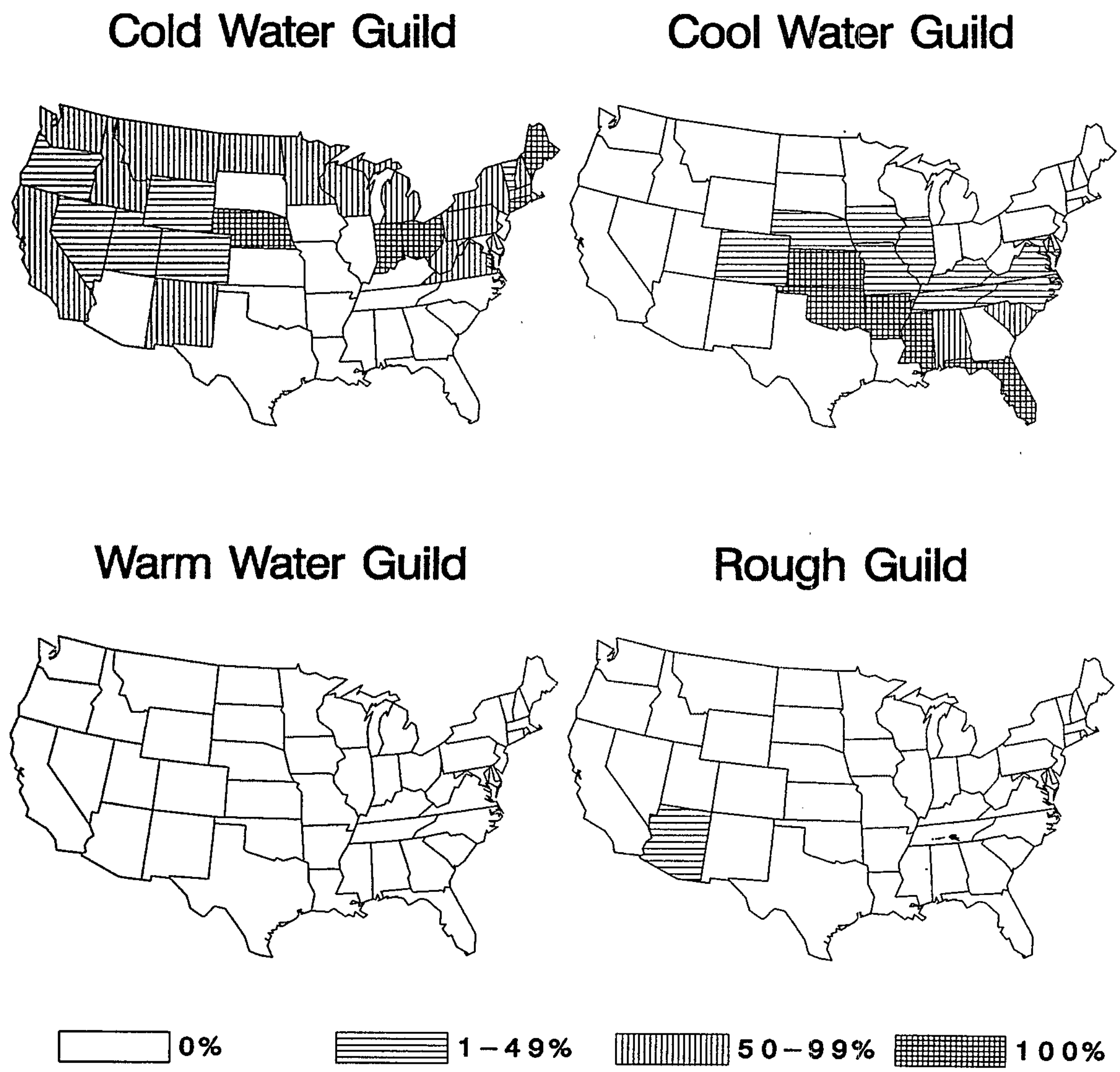


EXHIBIT F-3

Loss of Habitability for Cold Water Species

GFDL Transient Results - 2100

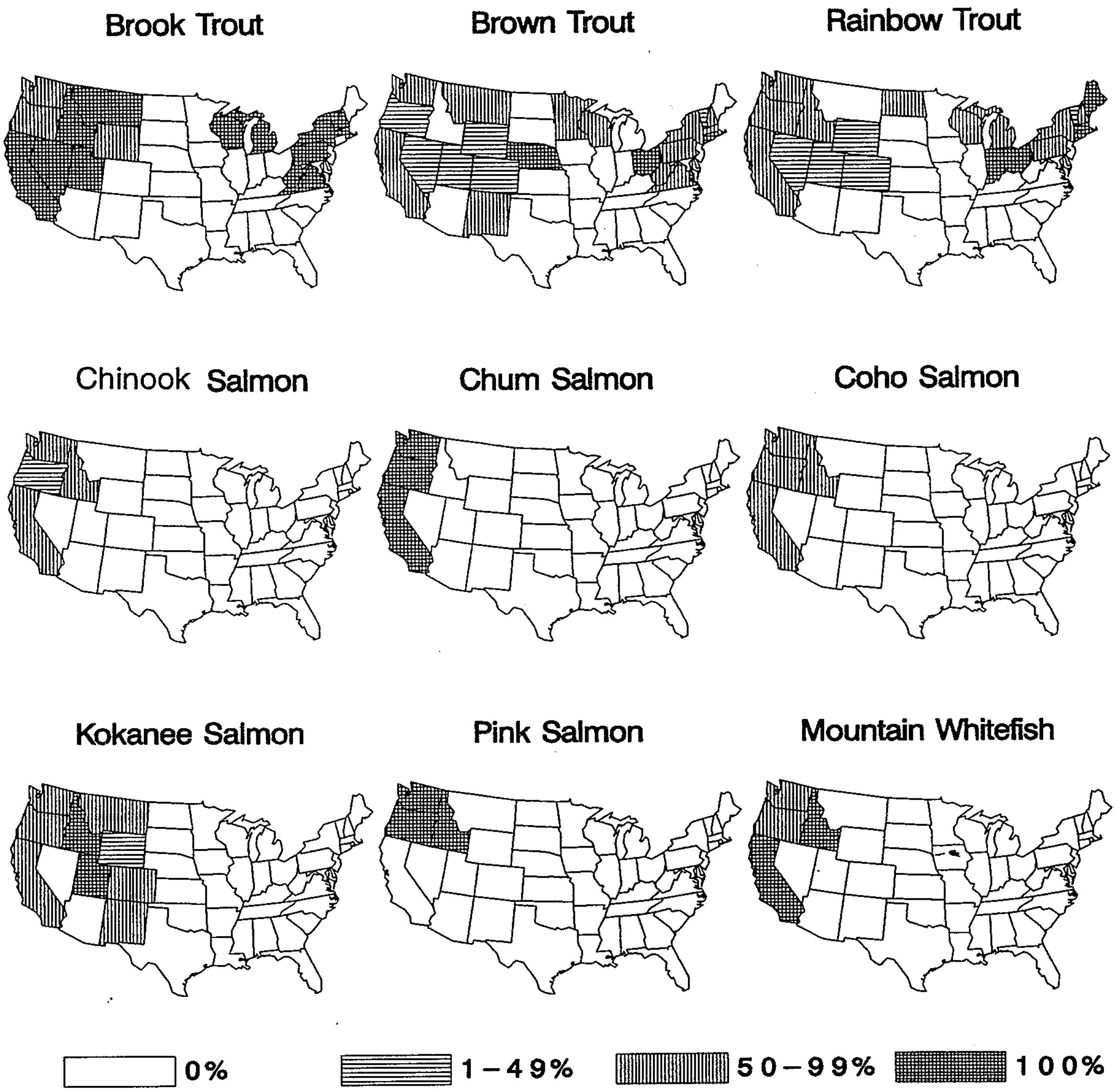


EXHIBIT F-4

Loss of Habitability for Cool Water Species

GFDL Transient Results - 2100

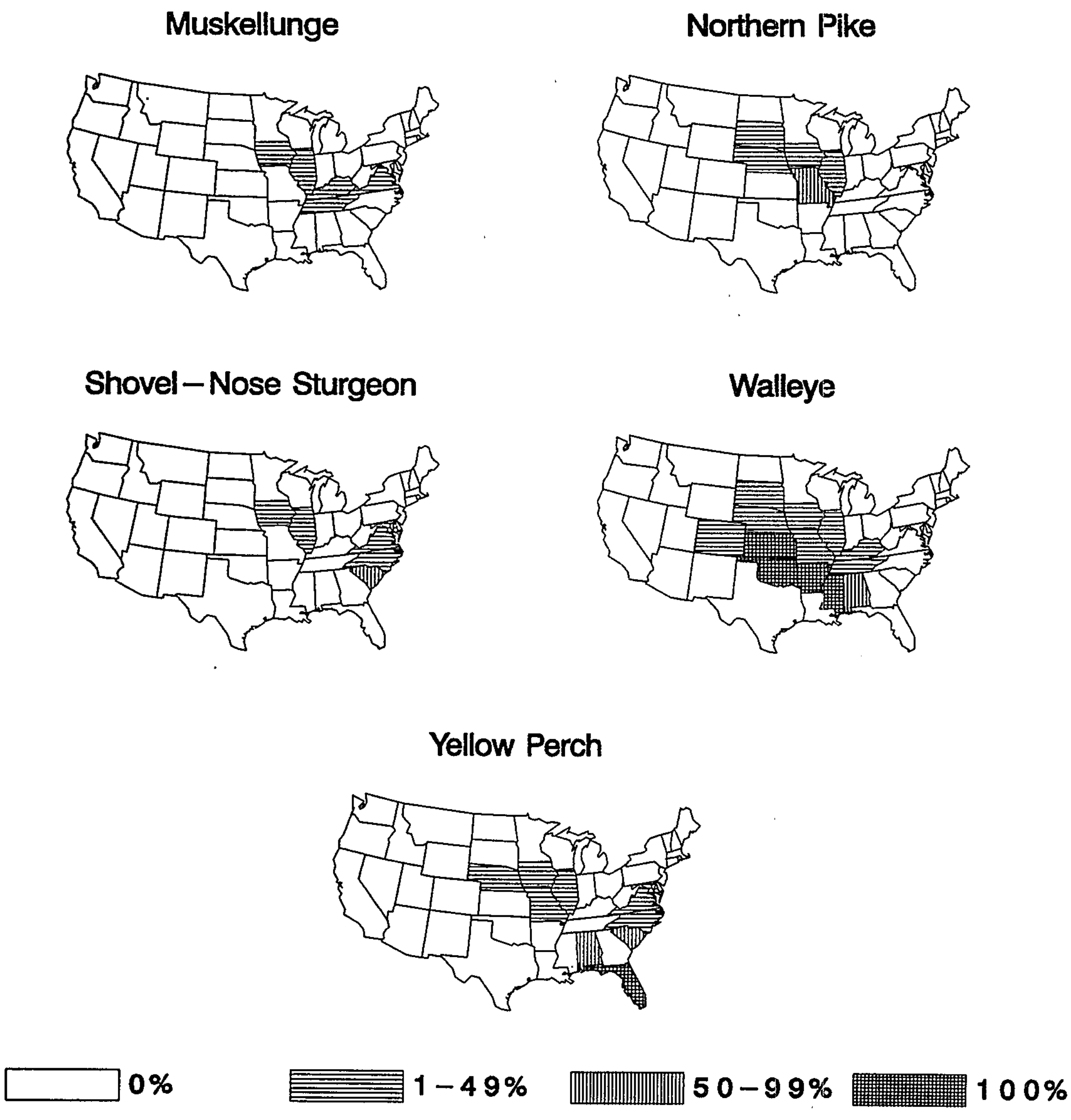


EXHIBIT F-5

Loss of Habitability for Warm Water Species

GFDL Transient Results - 2100

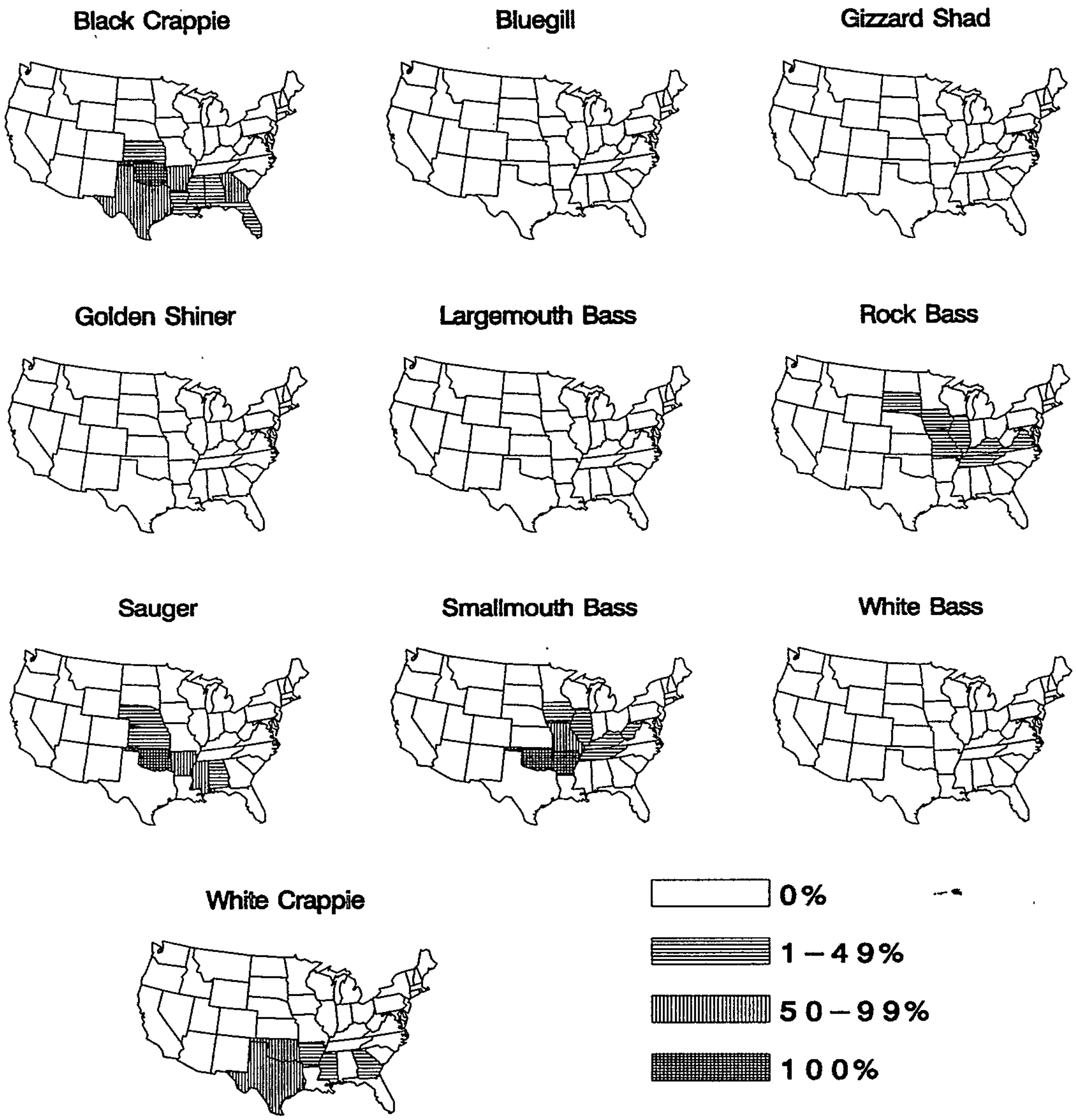
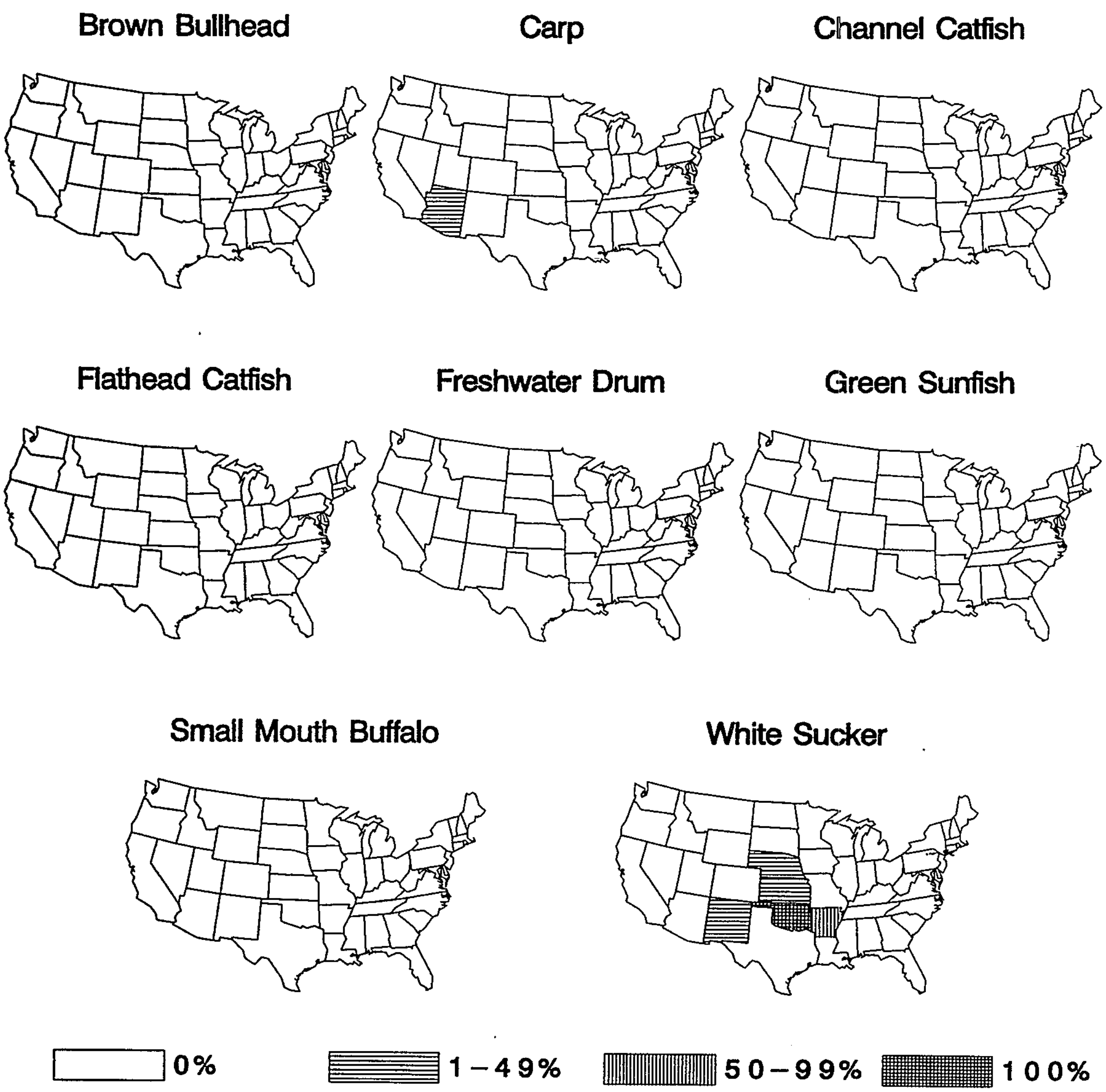


EXHIBIT F-6

Loss of Habitability for Rough Water Species

GFDL Transient Results - 2100



APPENDIX G

SUMMARY OF SELECTED ECONOMIC STUDIES OF THE VALUE OF FRESHWATER FISHING DAYS BY REGION

G. Summary of Selected Economic Studies of the Value of Freshwater Fishing Days

Appendix G provides a brief assessment of current empirical methods employed to value recreational fishing days and then presents a summary of selected economic studies that value freshwater fishing days within the United States. The research discussion and presentation of study results are meant to serve as supplements to the Chapter 3 discussion of the implementation of the economic model. The designation of values for coldwater, coolwater, warmwater, and rough fishing days was complicated by the limited number of nationally representative studies, the limited number of studies that derive values for different types of fish species, and the variation in estimated values across studies for single fish species.

G.1 Empirical Methods

Tbere are two primary mechanisms for deriving fishing day values: (1) travel cost methods (TCM) and contingent valuation methods (CVM). Travel cost studies are based on the implicit trading of travel and time costs for access to fishing sites and rely on the existence of widespread variation in travel costs across individuals and fishing sites to assess recreational values. Within this methodological category, there are two different fundamental approaches to modeling travel cost behavior: continuous neoclassical models and discrete choice continuous models. Numerous styles of both of these models have surfaced in the environmental economics literature. Distinctions in style are often connected with unique interpretations of travel or time costs, functional form specifications, and the treatment of substitute or alternative recreational sites (Freeman, 1993a, Bockstael et al., 1988). Contingent valuation studies are based on individual responses to hypothetical situations. These studies directly ask individuals what they would be willing to pay for some hypothetical change in the natural resource and in turn the recreational service flows.

Travel cost methods and contingent valuation methods are respectively referred to as imputed and indirect market valuation methods. While travel cost methods focus on the explanation of observed trips to sites based on variations in travel costs and site quality, contingent valuation methods rely on hypothetical surveys and intended payments (Walsh et al., 1992). When comparing these two types of studies, it might be expected that travel cost values are higher than contingent values because the travel cost estimates reflect the value of the entire trip while the contingent values capture only the value of the recreational activity.

Questions have arised regarding the appropriateness of different methods employed to determine recreational fishing site and day values. Travel cost methods ulimately often use some form of consumer surplus measure (i.e., average consumer surplus) to arrive at fishing day values. Several studies address the limitations of these continuous neoclassical approaches (i.e., Morey 1994). Alternative methods to derive site values have been developed. These methods involve gleaning indirect utility functions and calculating exact welfare measurements using discrete choice frameworks (i.e, Bockstael et al., 1986). The continuous neoclassical models appear more suited for analyses where individuals visit many of the sites sampled and visits are common across individuals. In turn, the discrete choice models place greater emphasis on corner solutions (i.e., zero visits) and substitutability across sites (Bockstael et al., 1988).

Several attempts (Walsh et al., 1992, Smith and Kaoru 1990) have been made to address concerns with the valuation of recreational days such as explaining differences in estimates across techniques, determining the appropriateness of different techniques, and assessing what types of factors influence the appropriateness decision. Variations in estimates are often associated with differences in the characteristics of the anglers, the quality of sites, or the research methods used for estimation.

G.2 Summary of Selected Empirical Studies

The discussion presented here relies heavily on American Fisheries Society 1993 and Walsh et al., 1992. Both of these works review several empirical studies and make revisions to the valuation estimates to allow for some form of meaningful comparison across studies. Using travel cost values, the recreational fishing day value is calculated by dividing the trip value by the reported number of days per trip. Alternatively, annual values are divided by rates of participation or household values are divided by number of persons and days of participation per person. Adjustments are made to reported study values to account for the omission of travel time in travel cost studies, the use of individual observations in travel cost methods, the arbitrary restriction of sample to in-state residents, the omission of a protest mechanism in contingent valuation studies, and the dollar basis for value estimates (American Fisheries Society, 1993).

The range of fishing day value estimates across methods, geographical areas, and fish species is made clear by Exhibit[SELFVAL] which summarizes the results from a select group of recreational valuation studies. The studies are organized by region and for each study the reference, value, method, fishing type, and modeling scale are presented. Travel cost and contingent valuation studies are represented in the table. It is important to that note that in the context of this analysis the global climate scenarios are linked with changes in the numbers of four different types of recreational fishing days: cold water, cool water, warm water, and rough. This economic structure necessitates the derivation of four unit values.

Reviews of the empirical literature suggest that certain species, types of fishing, and areas of the country have been better studied than others. For example, trout fishing has been broadly studied as has salmon fishing. In contrast, warm, cool, and rough species have been less well studied. These research tendencies complicate the derivation of fishing day values on a national basis by broad activity area and limit the way in which the economic model could specify fishing day values. There are virtually no studies that assess values for the four fishing categories of interest to the economic model. In addition, there is wide variation in estimates for single species across and within regions and estimation method types and little theoretical basis for deeming one value better than other. These and other issues shaped the designation of the primary, high, and low fishing day value specifications outlined in Chapter 3.

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region (1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
New England and Mid-Atlantic States (CT,DE,KY,ME,MD,MA,NH,NJ,RI,VT,VA,WV)				
Brown and Hay (1987)[2]	Connecticut 13.22 Delaware 18.18 Kentucky 21.49 Maine 14.87 Maryland 21.49 Massachusetts 14.87 New Hampshire 11.57 Rhode Island 14.87 Vermont 11.57 Virginia 18.18 West Virginia 18.18	CVM[3]	Freshwater Trout	USA by State
Hyatt (1984)[2]	Bait 10.03 Fly 14.22 Lure 12.42	CVM[5]	Freshwater Bait, Fly, and Lure Trout, Bass, Pickerel, and Panfish	Connecticut Farmington River
Kay et al., (1987)	39.42	CVM[5]	Anadromous Salmon	New England
South Atlantic and Gulf Coast (AL,AR,FL,GA,LA,MS,NC,SC,TN,TX)				
Bell (1979)[2]	19.71	CVM[3]	Freshwater General	Florida
Bell (1981)[2]	41.07	Hedonic	Warmwater General	Louisiana South-central
Bianchi (1969)[2]	13.28	TCM	Coldwater General	Kentucky

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region (1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
Brown and Hay (1987)[2]	Alabama 33.04 Arkansas 24.79 Florida 14.87 Georgia 16.52 North Carolina 16.52 South Carolina 13.22 Texas 39.66	CVM[3]	Freshwater Trout	USA by State
Gibbs (1974)[2]	42.81	TCM	Warmwater General	Florida
Miller and Hay (1984)[2]	38.01	TCM	Coldwater General	Maine
Ziemer and Hill (1980)[2]	39.02	TCM	Warmwater General	Georgia
West Coast (CA,OR,WA)				
Brown and Plummer (1979)[2]	Oregon 108.32 Washington 60.53	TCM, Hedonic	Coldwater General	Pacific Northwest Oregon Washington
Brown et al., (1965)[2]	56.11	TCM	Anadromous Salmon, Steelhead Trout	Oregon
Brown et al., (1983)	40.83	TCM	Coldwater Anadromous Steelhead Trout	Oregon Rogue River

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region (1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
Brown et al., (1984)	Oregon FW Salmon 29.70 Steelhead Trout 40.49 Washington FW Salmon 29.70 Steelhead Trout 40.49	TCM	Anadromous Salmon, Steelhead Trout	Pacific Northwest Oregon Washington
Brown and Shaloof (1986)[2]	Oregon Salmon 29.80 Steelhead Trout 40.64 Washington Salmon 29.80 Steelhead Trout 40.64	TCM	Freshwater Salmon, Steelhead Trout	Oregon, Washington
Brown and Hay (1987)[2]	California 26.44 Oregon 19.83 Washington 18.18	CVM[3]	Freshwater Trout	USA by State
Huppert et al., (1989)	TCM 68.99-334.78 CVM[4] 55.42	TCM/CVM	Anadromous Salmon Striped Bass	California Sacramento-San Joaquin River System
Wade et al., (1988)[2]	23.80	TCM	Coldwater General	California

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region (1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
Mountain (CO,ID,MT,ND,NV,SD,WY)				
Brown and Hay (1987)[2]	Colorado 21.49 Montana 19.83 North Dakota 19.83 Nevada 25.09 South Dakota 19.83 Wyoming 14.87	CVM[3]	Freshwater Trout	USA by State
Donnelly et al., (1985)[2]	TCM 20.88 CVM[3] 29.64	TCM and CVM	Freshwater Steelhead Trout	Idaho
Duffield et al., (1987)[2]	Lakes 90.83 Streams 133.82	TCM	Coldwater General	Montana
Gordon (1970)[2]	17.00	TCM	Coldwater General	Idaho
Hansen (1977)[2]	25.09	CVM[5]	Coldwater General	Intermountain Region Utah, Idaho, Wyoming, and Nevada
Johnson and Walsh (1980)[2]	19.31	CVM[3]	Coldwater General	Colorado
Johnson and Walsh (1988)[2]	13.61	CVM[3]	Coldwater Trout	Colorado Cache la Poudre River
Loomis and Sorg (1985)[2]	32.30	CVM[3]	Coldwater Anadromous Steelhead Trout	Idaho
Miller and Hay (1984)	44.62	TCM	Coldwater General	Idaho

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region
(1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
Sorg and Loomis (1986)[2]	Coldwater CVM[3] 20.82 TCM 37.33 Warmwater CVM[3] 17.56 TCM 38.28 Steelhead Trout CVM[3] 29.64 TCM 20.88	TCM, CVM	Warmwater Coldwater General	Idaho
Sorg et al., (1985)[2]	CVM[3] Mixed 16.82 TCM Cold, Mixed 36.47 Warm, Mixed 39.74	TCM, CVM	Coldwater Warmwater General	Idaho
Walsh and Olienyk (1981)[2]	14.77	CVM[3]	Coldwater General	Colorado
Walsh et al., (1980a)[2]	16.50	CVM[3]	Coldwater General	Colorado
Walsh et al., (1980b)[2]	22.96	CVM[3]	Coldwater General	Colorado
Walsh et al., (1980c)[2]	21.36	CVM[3]	Coldwater General	Colorado

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region (1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
Great Lakes				
Dutta (1984)	7.11	TCM	Freshwater Lake	Ohio Lake Erie
Hushak and Jeng (1990)[2]	17.33	TCM	Freshwater Private Boat Walleye, Yellow Perch	Ohio Lake Erie
Hushak et al., (1988)[2]	TCM Walleye 5.61 Perch 4.61	TCM	Warmwater Walleye, Yellow Perch, White Bass	Ohio Lake Erie
Great Lakes States (IL,IN,MI,MN,NY,OH,PA,WI)				
Brown and Hay (1987)[2]	Illinois 28.09 Indiana 14.87 Michigan 16.52 Minnesota 23.14 New York 14.87 Ohio 11.57 Pennsylvania 13.22 Wisconsin 32.29	CVM[3]	Freshwater Trout	USA by State
Buerger et al., (1986)	138.41	TCM	Anadromous Striped Bass	New York
Kalter and Gosse (1969)[2]	61.62	TCM	Coldwater General	New York
Krieger (1989)[2]	23.88	TCM	Freshwater Trout	Michigan Pigeon River

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region (1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
Menz and Wilton (1983)[2]	River 112.15 Lake 29.64	TCM	Coolwater Muskellunge	New York St. Lawrence River and Chautauqua Lake
Miller and Hay (1984)[2]	47.92	TCM	Coldwater General	Minnesota
Mullen and Menz (1985)[2]	48.77	TCM	Coldwater General	New York Adirondacks Region
Violette (1985)[2]	95.56	TCM	Lakes, Rivers, Ponds, and Stream General	New York Adirondacks Region
Midwest and Great Plains (IA,KS,MO,NB,OK)				
Brown and Hay (1987)[2]	Iowa 33.04 Kansas 28.09 Missouri 21.49 Oklahoma 33.05	CVM[3]	Freshwater Trout	USA by State
Weithman and Haas (1982)[2]	21.36	TCM	Coldwater	Missouri Lake Taneycomo
Southwest (AZ,NM,UT)				
Boyle et al., (1988)[2]	49.06	CVM[4]	Coldwater General	Arizona
Brown and Hay (1987)[2]	Arizona 18.18 New Mexico 23.14 Utah 18.18	CVM[3]	Freshwater Trout	USA by State
Fiore and Ward (1987)[2]	31.76	TCM	Coldwater Bass, Catfish, Walleye	New Mexico Elephant Butte Reservoir

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region (1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
Martin et al., (1974[2]	Warmwater 164.55 Coldwater 179.64	TCM	Warmwater Bass, Catfish Coldwater Trout	Arizona
Hansen (1977)[2]	25.09	CVM[5]	Coldwater General	Intermountain Region Including Utah
King and Walker (1980)[2]	18.27	TCM	Coldwater Trout	Arizona
King and Hof (1985)[2]	21.65	TCM	Streams and Reservoirs	Fort Apache Indian Reservation, Arizona
Miller and Hay (1984)[2]	57.84	TCM	Coldwater General	Arizona
United States				
Charbonneau and Hay (1978)[2]	CVM[4], TCM Bass 48.83, 100.22 Trout 53.96, 110.50 Anadromous 131.06, 161.89 Panfish 48.83, - Catfish 38.54, - Pike, Walleye 79.66, -	CVM, TCM	Freshwater Bass, Salmon, Trout, Northern Pike, Walleye, Panfish, Catfish	USA
U.S. Fish and Wild Service and Bureau of Census (1982)[2]	23.97	CVM[3]	Coldwater Trout	USA

Exhibit G-1
Summary of Selected Economic Studies of the Value of Freshwater Fishing Days by Region (1993 Dollars)[1]

Reference	Value	Method	Type of Fishing Species	Scale
Vaughan and Russell (1982b)[2]	Cold 44.81 Warm 39.79 Rough 29.76	TCM	Freshwater General	USA
Vaughan and Russell (1982c)[2]	Trout 58.24 Catfish 38.75	TCM	Freshwater General	USA

Notes:
[1] Values presented are average consumer surplus measures unless otherwise noted.
[2] Values have been standardized to allow for comparison using rules of thumb developed by Sorg and Loomis (1984) and updated by Walsh et al., (1988). Rules are outlined and values are presented in American Fisheries Society (1993). Adjustments involve treatment of travel time, individual observations, sample restrictions, protest mechanisms, and dollar values.
[3] Values presented are the average of net willingness to pay measures.
[4] Values presented are the average of total willingness to pay measures.

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