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Continental-Scale Projections of Potential Climate Change Effects on Small Lakes in the Contiguous U.S.

Vol. 3
Effects of Climate Conditions on Fish Habitat

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ABSTRACT

This study is concerned with the projection of climate change effects on lakes, especially small lakes with surface areas up to 10 km^2 and depths up to 24 m in the cold regions of the contiguous U.S. In this study, we have chosen lake parameters which are most directly influenced by climate and which in turn have much influence on aquatic lifeforms, water quality and water uses. The first two parameters studied were lake water temperature (T) and dissolved oxygen (DO) concentration. They have been estimated for past (1961-1979) climate conditions (Vol. 1 of this report) and a projected $2xCO_2$ climate scenario (Vol. 2). Subsequently fish habitat in lakes, as constrained by T and DO, has been studied herein. In this Volume 3 of the report, water temperature and DO criteria (limits) of survival and good-growth of three fish assemblages (cold-water, cool-water, and warmwater), and parameters that quantify fish habitat in lakes in response to T and DO limits are given. Fish habitat was simulated in 27 types of lakes at 209 geographic locations over the contiguous U.S. under different climate scenarios. It includes a validation of fish habitat simulations against fish observations and a sensitivity analysis of simulated winter fish habitat to three DO survival limits.

A verified, process-oriented, unsteady and one-dimensional (vertical) year-round lake water quality model (MINLAKE96) was used for temperature and DO simulations. The twenty-seven (27) types of lakes chosen differed by surface area (A_S), maximum depth (H_{MAX}), and Secchi depth (z_s, a common limnological measure of lake transparency). These three parameters are known to have a crucial influence on water temperatures and DO concentrations, and further alter fish habitat in lakes. The Secchi depth was related to radiation attenuation as well as trophic state of a lake. This is a major assumption that will not hold true in lakes which show turbidity from inorganic suspended sediments. Secchi depth was related to mean annual phytoplankton chlorophyll-a concentration in a lake (typical seasonal chlorophyll cycles were superimposed). This made it possible to estimate photosynthetic oxygen production without specification of nutrient inputs from the watershed. Lakes simulated were treated as having constant volume and long hydraulic residence times.

Daily temperature and DO profiles in lakes were simulated under both past (1961-1979) climate and a projected $2xCO_2$ climate scenario. Simulated results were reported in Volumes 1 and 2 of this report. To project a future $2xCO_2$ climate scenario, monthly increments or ratios of climate parameters derived from the Canadian Climate Center (CCC) General Circulation Model (GCM) were applied to measured past climate conditions from 1961 to 1979 following a protocol proposed by the U.S. Environmental Protection Agency. The second generation CCC GCM includes higher spatial resolution 3.75° x 3.75° than previous models and full diurnal and annual cycles. Daily weather records from 209 stations in the contiguous U.S. for the period of 1961-1979 were used to

represent past climate conditions. Elevations of the weather stations above sea level ranged from 2 m (Miami, FL) to 2135 m (Flagstaff, AZ). The weather stations used in this study are typically at airports, near towns. The lake simulations made are therefore not representative of alpine conditions, i.e. altitudes exceeding those of the weather stations used.

Fish habitat in lakes is strongly constrained by water temperature and available dissolved oxygen (DO). Suitable fish habitat for three fish assemblages was therefore determined from simulated daily water temperature and dissolved oxygen profiles for 27 types of lakes under past (1961-1979) and the projected $2xCO_2$ climate scenarios. Water temperature and DO criteria for survival and good-growth of each fish guild were provided by the United States Environmental Protection Agency. Simulated suitable fish habitats were compared with fish observations in 3002 lakes near Duluth and Minneapolis, Minnesota. Sensitivity of the simulated winterkill to three DO survival limits (0.0, 0.5 and 1.0 mg/l) was analyzed since winter DO limit for fish habitat is still not well defined.

Depth-time contours were developed to identify different fish habitat types (uninhabitable space, restricted growth habitat, and good-growth habitat) in lakes under past and projected climate scenarios. Fish habitat parameters were determined and plotted at selected individual geographic locations in a format that would show the influence of the three independent lake parameters (surface area, maximum depth, and Secchi depth) on simulated good-growth habitat parameters (good-growth length, good-growth habitat areas and volumes). Based on the variability of fish habitat parameters with lake parameters shown, several U.S. maps giving the geographic distribution of fish habitat parameters at 209 locations in the contiguous U.S. were then prepared. These U.S. maps give simulated fish habitats in specific lake type under past and projected $2xCO_2$ climate scenarios as well as their differences between projected and past climate scenarios.

In general, three pieces of information were extracted from the simulation results and summarized in this Volume 3 of the report: (1) Can fishes of a guild survive in a specific lake under each climate scenario? (2) If no, what will be the length of the good-growth period? (3) What will be the good-growth habitat areas and volumes integrated over time. The answers to these questions were provided for 27 types of lakes at 209 locations of the contiguous U.S. and for two climate scenarios over an 18-year period. The results show that the impact of projected climate warming on fish habitat is very significant in the northern half of the contiguous U.S.

The following conclusions stand out among the many study results:

(1) Climate warming is projected to eliminate winterkill (due to low DO) in shallow, eutrophic lakes in the contiguous U.S.

(2) Simulated good-growth periods, good-growth habitat areas and volumes for all three fish species depend more strongly on lake geometry ratio ($A_s^{0.25}/H_{max}$), which is a measure of the strength of stratification in a lake, than on lake trophic state (Secchi depth).

(3) In seasonally stratified lakes, the good-growth period for all three fish guilds is larger when the lake geometry ratio (strength of stratification) is smaller.

(4) While winterkill in shallow, eutrophic lakes under past climate conditions is projected to disappear under a $2xCO_2$ climate scenario, summerkill of cold-water fish in mesotrophic lakes due to elevated temperature is likely.

(5) Simulated good-growth periods for cold-water fish range from 3 to 12 months and decrease from northern to southern latitudes in the contiguous U.S. Climate warming is projected to shorten good-growth periods in most lakes, by up to 120 days.

(6) Climate warming is projected to reduce the geographic areas (number of locations), where lakes have suitable cold-water fish habitat, by up to 45%. Average reductions are 14%, 43%, and 31% for shallow (4m), medium-depth (13m), and deep (24m) lakes, respectively. Cold-water fish have the best chance to survive in deep, stratified lakes near the northern border of the contiguous U.S.

(7) Summerkill under the projected $2xCO_2$ climate scenario is a projected significant negative impact on cool-water fish in southern lakes of the contiguous U.S., where suitable habitat exists under present conditions.

(8) For cool-water fish, climate warming is projected to lengthen the good-growth period by up to 137 days in lakes in the north-central and northeastern states and to shorten it by up to 103 days in lakes of several south-central and southeastern states of the contiguous U.S. Projected increases (due to climate warming) of the good-growth period, the good growth habitat areas and volumes of cool-water fish in medium-depth lakes of the contiguous U.S. are on average 20%, 10% and 8%, respectively.

(9) Climate warming is projected to reduce the geographic areas (number of locations), where lakes have suitable cool-water fish habitat, by up to 30%. Average reductions are 27%, 20%, and 3% for shallow (4m), medium-depth (13m), and deep (24m) lakes, respectively.

(10) Cool-water fish can exist in many lakes of the contiguous U.S. Exceptions are shallow, eutrophic lakes in the north-central U.S. (winterkill) and in south-central U.S. e.g. Louisiana, part of Texas, south Arkansas and Alabama, parts of Georgia and Florid (summerkill). Summerkill in shallow lakes will expand significantly in south-central and southeastern states under a $2xCO_2$ climate scenario.

(11) Good-growth periods for cool-water and warmwater fish increase in length from northern to southern latitudes in the contiguous U.S. This relationship with latitude is inverse to the one found for cold-water fish.

(12) No summerkill of warmwater fish, due to elevated temperature and/or dissolved oxygen deficiency, is projected to occur in any lake and at any location of the contiguous U.S. investigated under both climate scenarios. Under the projected $2xCO_2$ climate scenario, the good-growth period for warmwater fishes extends from about 75 days at northern latitudes to an entire year (365 days) at southern latitudes.

(13) Climate warming is projected to have several positive effects on warmwater fish habitat in lakes of the contiguous U.S. For example, climate warming is projected to increase the good-growth period of warmwater fishes on average by 30 to 40 days in lakes at *all* locations investigated, more in deeper than in shallow lakes and more at northern than at southern latitudes. The highest relative increase of habitat areas/volumes with climate warming is over 200% and occurs at northern latitudes. In several southeastern states good-growth habitat areas and volumes are projected to decrease by up to 30% from the past values, which is the only negative impact of climate warming on warmwater fish found in this study.

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I. INTRODUCTION

Projected climate warming is expected to change aquatic/hydrologic systems most strongly in cold regions. This study is concerned with climate change effects on lakes in the northern regions of the contiguous U.S. We have chosen lake parameters which are most directly influenced by climate and which in turn have much influence on water quality, water uses and aquatic organisms, e.g. fish. The two main parameters studied herein are lake water temperature (T) and dissolved oxygen (DO) concentration. Fish habitat in lakes, as constrained by T and DO, was determined for past (1961-1979) climate conditions and a projected $2xCO_2$ climate scenario. This report (Volume 3) summarizes water temperature and DO criteria for survival and good-growth of fish assemblages (cold-water, cool-water, and warmwater), parameters that quantify fish habitat in lakes, and simulated, time-integrated fish habitat in different lakes in the contiguous U.S. under different climate scenarios. It includes a validation of fish habitat simulations against fish observations in 3002 Minnesota lakes and a sensitivity analysis of simulated, time-integrated winter fish habitat to three DO survival limits.

To make the study, we had to develop and apply process-oriented, simulation models, which link atmospheric conditions to lake water conditions. The development of these models began many years ago for individual lakes and was then expanded to lake assemblages in a region. At each level more and more field data were required and used to validate the models. In the process of generalizing the models, it was also necessary to specify "typical" lake characteristics in a region. Development and applications of the models have been summarized in several project reports (Stefan et al., 1994; Fang and Stefan, 1994, 1996c, 1996d; Stefan and Fang, 1995) and journal articles (Fang and Stefan 1996a, 1996b; Fang et al., 1996; Stefan et al., 1996). Before the models were applied at the continental-scale, the model formulations and assumptions were reviewed to examine what geographically variable parameters had to be introduced. The models used in this study were described in section 2 of Volume 1 (Fang and Stefan, 1996d) of this report.

The models developed were applied to 27 different types of lakes (Table 1). The lakes chosen differed by surface area (A_S), maximum depth (H_{MAX}) and transparency as measured by Secchi depth (z_s). These three parameters are known to have a crucial influence on water temperatures and DO concentrations. Distribution of the 27 lake types on a plot with the lake geometry ratio $A_S^{0.25}/H_{MAX}$ as abscissa and Secchi depth z_s as ordinate, as shown in Fig. 1, is more or less uniform. The likelihood of a strong or weak stratification in a lake can be related to the lake geometry ratio $A_S^{0.25}/H_{MAX}$ (Gorham and Boyce, 1989). The 27 types of lakes defined cover geometry ratios from 0.9 to 14.1 (Table 1). According to Gorham and Boyce (1989) well-mixed polymictic lakes have the highest geometry ratios, while strongly stratified (dimictic or monomicitc) lakes have the lowest geometry ratios. The transition occurs between 3 and 5. Hence the full range of stratification behavior of lakes is included in the lake types selected for study.

The lakes were assumed to be more or less round and to have "typical" area vs. depth distributions (Hondzo and Stefan, 1993). The Secchi depth was related to transparency as well as trophic state of a lake. This is a major assumption that will not hold true in lakes which show turbidity from inorganic suspended sediments. Secchi depth (z_s) was related to mean annual phytoplankton chlorophyll-a concentration in a lake. This made it possible to estimate photosynthetic oxygen production without specification of nutrient inputs from the watershed. Lakes were also treated as having constant volume and long hydraulic residence times.

To simulate the climate effect on fish habitat in these 27 lake types, weather data recorded at a representative number of locations in the contiguous U.S. and for a sufficiently long period of the past had to be found and used. Daily records from 209 stations during the period 1961-1979 were used. Distribution of the weather stations based on their longitude and latitude is shown in Fig. 2, a U.S. base map with state boundaries. The 209 stations and other associated information are listed in Appendix A. Longitude of the weather stations ranged from 68°1'W to 124°33'W and latitude from 25°48' to 48°34'N. Most of these 27 types of simulated lakes do not actually exist at the 209 locations investigated. In many locations the lakes studied are hypothetical lakes. However, this "generic" approach gives a good picture of how different lake types may behave in different parts of the country, especially under a $2xCO_2$ climate scenario for which there are no lake data. The generic approach is a valuable and necessary alternative to the study of individual, 'real' lakes. Studies of individual 'real' lakes, found in different parts of the U.S. and exposed to a rang of climate conditions have been conducted by several investigators, including the authors, but it may be uncertain how the results can be transferred from one 'real' lake to another. Because of the uncertainty of future climate and runoff projections, it is also not obvious or easy to determine whether 'real' lakes will become deeper or more shallow, more eutrophic or less under changed climate and runoff conditions. For these reasons the study of generic lake types, allowing interpolations among them, is a valuable supplement to the study of individual real lakes.

Elevation of the weather stations above sea level ranged from 2 m (Miami, FL) in the coastal areas to 2,135 m (Flagstaff, AZ) in the mountainous areas (Fig. 3). The weather stations used in this study are typically at airports, near towns, and are therefore representative of those altitudes and locations. They are not representative of mountain tops and alpine conditions. The lake simulations made will therefore also not be representative of alpine conditions, i.e. altitudes exceeding those of the weather stations used.

Simulation results of water temperatures and dissolved oxygen concentrations in lakes were obtained at each location and for each lake type on a daily timescale for 18 years. The results were then averaged for each day of the 18-year simulation period (the first year of simulation was excluded to eliminate initialization errors). Results in this report are therefore long-term (18-year) averages under past and projected $2xCO_2$ climate scenarios. The period from 1962 to 1979 was used as the no climate change (base) period (worldwide air temperature data show an upward trend beginning in 1980, Jones et al., 1986; Kerr, 1989). The basic simulation results from year-round water quality models are 18-year averages of daily water temperature and DO profiles in lakes, ice thicknesses, and cumulative water losses. Modeling procedures and simulation results for past climate conditions were summarized in Vol. 1 of the report (Fang and Stefan, 1996d).

The projected $2xCO_2$ climate scenario was derived from the output of the Canadian Climate Center (CCC) General Circulation Model (GCM) (McFarlane et al., 1992; Boer et al., 1992) for a doubling of atmospheric CO_2. The second generation CCC GCM includes higher spatial resolution 3.75° x 3.75° than previous models (e.g. GISS – Goddard Institute for Space Studies at Columbia University) and full diurnal and annual cycles. The CCC GCM grid center points within or near the contiguous United States are shown in Fig. 2 (crosses) and plotted together with the 209 weather stations (dots) used in the continental-scale simulations. Simulation results under the projected $2xCO_2$ CCC climate scenario were summarized in Vol. 2 of the report (Fang et al., 1997).

Monthly increments for air temperature and ratios for solar radiation, wind speed, relative humidity, and precipitation between the $1xCO_2$ and $2xCO_2$ climate scenarios were calculated from the CCC GCM output. These monthly weather parameter increments or ratios were then applied to measured present climate conditions (1961 to 1979) to generate the projected $2xCO_2$ daily climate scenario. This procedure eliminates model bias and was proposed by the USEPA (Smith and Tirpak, 1989). Monthly increments or ratios from the CCC GCM grid center point closest to a weather station (based on distance using longitude and latitude as coordinates) were used. Therefore the same mean monthly adjustments could be used for two or more weather stations if they are all close to a particular grid center point (CCC GCM). A summary of geographic and time distributions of weather parameters for past and the projected $2xCO_2$ climate scenario were shown in Volume 1 of the report (Fang and Stefan, 1996d).

In order to estimate fish habitat in lakes, water temperature and DO criteria for three fish guilds (cold-water, cool-water, and warmwater) were established. These water temperature and DO criteria were matched with the simulated daily year-round water temperature and DO profiles in lakes. Three fish habitats (uninhabitable space, good-growth habitat and restricted growth habitat) for each guild were thereby identified. From the resulting depth vs. time distributions of the isolines which delineate these different habitats (Figs. 7 to 15), more easily interpretable and useful fish survival and growth parameters, summarized and defined in Table 3, were extracted. This was done for 27 lake types at 209 geographic stations in the contiguous U.S. Values of these parameters are listed in Tables 4 to 17 for four geographic locations (Duluth and Minneapolis, MN, Kansas City, MO, Austin, TX, shown in Fig. 4). These fish survival and growth parameters were also plotted for four selected weather stations (Duluth, MN, Boulder, CO, Charleston, WV, and Austin, TX) in a format, which can show the influence of three significant independent lake parameters (surface area, maximum depth, and Secchi depth). Based on the variability of fish habitat parameters with each lake parameter, several U.S. maps giving the geographic distribution of good-growth fish habitat parameters were then prepared for each fish guild. In the process a validation of fish habitat simulations against fish observations in 3002 Minnesota lakes and a sensitivity analysis of simulated, time-integrated winter fish habitat to three DO survival limits were investigated. The overall simulation procedures for water temperature, dissolved oxygen concentration, and fish habitat in a lake were schematically summarized in Fig. 5 (from Stefan et al., 1994).

The results given in this report (Volume 3 of the study) include: (1) a series of graphs and tables showing the simulated, time-integrated fish survival and growth parameters for several or all 27 lake types investigated at a few selected locations; (2) U.S. maps showing the fish survival and growth parameters for a few lake types at all geographic locations in the contiguous U.S. under past and projected $2xCO_2$ climate scenarios and their differences; and (3) results of model validation and sensitivity analysis for fish habitat prediction.

II. METHOD OF ESTIMATING FISH HABITAT

II.1. Water Temperature and DO Criteria for Three Fish Guilds

Lake water temperature and its variation represents the thermal state of a lake as a result of heat inputs, losses, and exchange. For example, solar radiation and atmospheric long wave radiation add heat to a lake, while evaporation and back radiation cool the water. Lake water temperature responds to meteorological conditions and has a significant influence on water quality and ecology of lakes. It directly affects fish survival and growth in lakes. For example, the National Water Quality Criteria (National Academy of Science and National Academy of Engineering, 1972) indicate the importance of acclimation temperature for fish species, that is the temperature to which fish has become accustomed.

Water temperature criteria for three fish guilds were available from laboratory and field studies as described by Eaton et al. (1995). The guild designations for various fish species as suggested by Hokanson (1977) were adopted. Table 2 summarizes three temperature levels for fish guilds: the lower good-growth temperature limit (LGGT) and the upper good-growth temperature limit (UGGT), the lethal temperature threshold (LT), and the optimum temperature (OT). Fish have good growth potential when water temperature falls between the lower and the upper good-growth temperature limits. In order to determine LGGT and UGGT, a curve was developed to fit laboratory growth rate data for individual fish species when sufficient experimental data were available (Eaton et al., 1995). The LGGT is the mean temperature between zero net growth and maximum growth, and the UGGT is the optimum temperature plus 1/3 of the ultimate incipient lethal temperature minus optimum temperature (USEPA, 1976). The upper lethal temperature threshold LT is the water temperature that fish cannot be acclimated to without causing death. In essence, the LT was determined from field data that relate maximum annual water temperature to fish presence (Eaton et al., 1995). The optimum temperature (OT) is a water temperature at which fish have maximum physiological "strength".

The above temperature values can be obtained for many individual fish species, e.g. chinook salmon, brook trout, bluegill, smallmouth bass and channel catfish (NAS/NAE, 1972). In this study fish species have been grouped into cold-water, cool-water, and warmwater fish guilds (Hokanson, 1977). Table 2 gives temperature limits for these three fish guilds, which comprise a total of 29 species. Guild values are the means of available LT, LGGT, UGGT and OT values for species in each guild. Ranges of the above temperature criteria for species in each guild are also shown in Table 2.

The availability of suitable dissolved oxygen (DO) concentrations can also control the presence or absence of a freshwater fish species in a lake (Coutant, 1990; Chapman, 1986), because an adequate DO concentration is essential for metabolism of all aerobic aquatic organisms. Fish guilds have DO concentration requirements (Table 2), below which mortality is more likely to occur or growth is impaired (USEPA, 1976). The dissolved oxygen criteria for three fish guilds summarized in Table 2 were provided by the USEPA and used in previous studies (Stefan et al., 1992). The DO criteria were developed from an available USEPA database (Chapman, 1986) plus expert consultation. The detectable lethalities in 96 hours exposures (acute mortality limit) representative for non-salmonid species (i.e. cool- and warmwater species) occur between 2.5 mg/l and 4.5 mg/l of DO concentration (Chapman, 1986). The selected DO criteria values are 2.5 mg/l for warmwater species and 3.0 mg/l for cool-water species (Table 2). The acute lethal limit for salmonids is at or below 3mg/l (Chapman, 1986), therefore the DO criteria for cold-water species was set to be 3.0 mg/l. Since DO criteria used in this study are for acute mortality limits, they are lower than national DO criteria suggested by the USEPA (1985) (0.5 mg/l above DO criteria for "slight reproduction impairment" protection or risk).

DO criteria summarized in Table 2 were developed for the open water season. For ice-cover lakes, DO concentrations diminish over time during the winter due to sedimentary oxygen demand and water column oxygen demand. Ice cover prevents oxygen exchange (reaeration) between the atmosphere and the water. With a snow/ice cover on a lake, solar energy is very strongly attenuated and photosynthetic oxygen production is therefore minimal. In shallow, eutrophic lakes DO concentrations can therefore drop below 2.0 mg/liter near the end of an extended ice cover period. The low DO concentration is a major factor to significantly influence presence or survival of fish assemblages in ice-cover lakes of cold regions (e.g. Minnesota, Wisconsin, Michigan and Maine). The death of fish due to oxygen depletion under ice (winterkill) is a significant fisheries management problem in shallow lakes, both in the north-central United States and Canada (Johnson, 1970; Schneberger, 1970). For example hundreds of lakes are annually threatened by winterkill in the state of Minnesota where nearly 200 aeration permits were issued for every winter since 1988 (Ellis and Stefan, 1991).

For ice-cover lakes, DO criteria for fish survival could be set at lower values, but data from previous studies are still inadequate to establish specific tolerance limits of dissolved oxygen for fish winterkill (Greenbank, 1945; Barica and Mathias, 1979). In this study, ***the same DO criteria*** have been used for the open-water season and the ice-cover period. A sensitivity of fish habitat during the winter to three DO survival limits is, however, investigated in section III.2.

II.2. Definition of Fish Survival and Growth Parameters

Fish habitat has several inter-dependent physical and biological characteristics (Rundquist and Baldrige, 1990). The presence or survival of fish in a lake is, in general, related to accessibility, suitable ecological conditions for human interference, and resistance to episodic natural events (Fry, 1971). Water temperature, channel geometry and stream-flow are important to fish habitat in streams (Rundquist and Baldrige, 1990). In lakes water temperature and DO concentration are two of the most significant water quality parameters affecting and controlling survival and growth of fishes (Fry, 1971; Magnuson et al., 1979, 1990; Coutant, 1985, 1987; Christie and Regier, 1988).

Simulation procedures for daily water temperature and dissolved oxygen profiles in lakes are schematically shown in Fig 5. A verified, deterministic, process-oriented, unsteady and one-dimensional (vertical) lake water quality model (MINLAKE96, Fang and Stefan, 1996c and 1996d) was used for these simulations. In cold regions the model simulates ice and snow covers on a lake. The lake parameters required as model input are surface area, maximum depth, and Secchi depth as a measure of radiation attenuation and trophic state. The model is driven by daily weather data. The simulations were carried out for 209 locations in the contiguous United States with 1961-1979 weather data as input. Simulations were then repeated with the projected 2xCO_2 (CCC GCM) climate scenario at the same stations. Since the main objective of the investigation was to identify "normal" fish habitat (Hondzo and Stefan, 1996) in response to time-variable climate conditions, the simulated daily water temperature and dissolved oxygen profiles were averaged over a 18-year simulation period. Simulation results for the first year, 1961, were excluded to eliminate any carry-over from initial conditions.

Fish thermal and DO survival and good-growth criteria specified in Table 2 were applied to the simulated 18-year average daily water temperature and DO profiles as shown schematically in Fig. 6a, developed for a lake *with fish presence* during the open-water season (Hondzo and Stefan, 1996). Low DO concentrations near the lake bottom in summer force fish upward, and warm water temperatures near the water surface force fish downward in search of conditions for survival. When isolines of lethal temperature (LT) and DO limits for a fish species intersect each other, uninhabitable space exists over the entire depth of a stratified lake. Summerkill of a fish species in a lake is expected to occur if such non-survival conditions last more than seven days (Fig. 6b). When the maximum surface water temperature is lower than the LT, the isotherm for LT will not show up. In that case the Do survival limit becomes the only survival criterion. The DO survival limit (isopleth) can occur not only during the open-water season (summer) but also in the ice-cover period (winter) (Figs. 7 to 15). Three isotherms extracted designate the survival temperature (LT), the upper good-growth temperature (UGGT) and the lower good-growth temperature (LGGT), respectively. Between those isolines, three fish habitats are identified:

(1) *Uninhabitable space* if temperature is above or DO is below the survival limit.

(2) *Good growth habitat* if temperature is between the upper and lower good-growth limits (i.e. LGGT < T < UGGT) and DO is above the survival limit.

(3) *Restricted growth habitat* if temperature is above the upper growth temperature but below the survival limit (i.e. UGGT < T <LT), or if temperature is below the lower good-growth limit of temperature (i.e. T < LGGT), and if DO is above the survival limit.

Graphical presentations of these three habitats in selected lake types under both past and projected climate scenarios will be shown in Figs. 7 to 15 for each of the three fish guilds (cold-water, cool-water, and warmwater fish). To quantify the graphical information on fish habitat in Figs. 7 to 15 and for easier comparison and interpretation, ***nine fish-habitat parameters*** defined in Table 3 were extracted. Four of these were dates (GSB, GSE, NSB, and NSE) as schematically shown in Fig. 6b, which is for a lake with ***non-survival conditions*** at all depths during the summer. GSB and GSE mark the beginning and the end of the good-growth season, NSB and NSE indicate the beginning and the end of non-survival at all depths in a lake, respectively. NSB and NSE can occur during the open-water season (Fig. 6b, Hondzo and Stefan, 1996) or during the ice-cover season. With models available to simulate water temperature and DO concentration over the entire year, the season in which NSB and NSE are occurring (open water-season or ice-cover period), can be identified in Figs. 7 to 16. These NSB and NSE bracket the fish "summerkill" or "winterkill", the latter primarily due to low DO values.

The total number of days for non-survival and the total number of days for good-growth were labelled as NSL and GSL, respectively (Fig. 6b and Table 3). NSL is the total number of days when in the vertical lake profile either temperature or dissolved oxygen do not meet the fish presence criteria at all depths. NSL defines the length of summer and winter periods of non-survival or the length of time that fish presence criteria are not met. NSL is the summation of differences between NSE and NSB during the winter and the summer seasons. GSL is the total number of days when simultaneously any value of temperature is between the lower and upper good-growth bound in the vertical temperature profile, and dissolved oxygen exceeds the limit in the dissolved oxygen profile. GSL only occurs in the open-water season because water temperatures during the ice-cover period are always less than the lower good-growth limits (LGGT) for all three fish guilds. GZER is used to quantify the midsummer period of reduced growth potential, stress and possible death. It includes the summer NSL period. GZER is the total number of days when simultaneously the upper limit for good-growth temperature and the dissolved oxygen survival limit are exceeded in the lake profile. GSL is equal to GSE minus GSB excluding GZER (Fig. 6b), and can occur in two separate periods: early summer (G_{SL1}) and late fall (G_{SL2}, Fig. 6b).

The foregoing seven habitat parameters are all in units of time (days). Since water quality (temperature and DO) varies with depth in stratified lakes, two additional parameters related to fish growth potential were defined (Table 3). *Good-growth habitat area (GGHA)* is defined as lake **bottom areas** (m^2) integrated over time (days) where and when (a) water temperatures are within the upper and lower good-growth temperature limits and (b) dissolved oxygen is above the survival limit. Integration begins at the first exceedance of the lower good-growth limit of temperature (LGGT) provided DO is above the survival limit. The integral in m^2-days is divided by surface area A_S (m^2), to give a ***normalized GGHA*** in units of days. *Good-growth habitat lake volume (GGHV)* is defined as **lake volumes** (m^3) integrated over time (days) where and when (a) water temperatures are within the upper and lower good-growth temperature limits and (b) dissolved oxygen is above the survival limit. The integral in m^3-days is divided by surface area A_S, to give a ***normalized GGHV*** in units of meter-days. These two parameters are the summation of possible good-growth areas and volumes for fish species over a growing season, respectively. Good-growth habitat areas and volumes measure thermal habitat space and were developed by Christie and Regier (1988) as predictor variables to estimate the total sustained yields of four commercially important fish species (lake trout, lake whitefish, walleye, and northern pike). These two parameters integrate a lake's volume-area-depth relationship (lake morphometry) with water temperature variation with depth to become useful fish habitat parameters (Stefan et al., 1995). A FORTRAN program in Appendix B was developed to extract four isolines from daily water temperature and DO profiles over the entire year and to estimate the above nine fish habitat parameters.

III. Projected Fish Habitat at Selected Geographic Locations

III.1. Distribution of Fish Habitat with Lake Depth and Time

Depth-time contours (Figs. 7 to 15) of fish habitat were extracted from the simulation results for three selected locations from northern to southern latitudes in the central United States: Duluth, Minnesota (92°11'W, 46°50'N), Kansas City, Missouri (94°43'W, 39°18'N), and Austin, Texas (97°42'W, 30°18'N) (see their locations in Fig. 4). Simulated fish habitat for past (1961-1979) climate and a projected 2xCO_2 CCC climate scenario is presented side by side for easy comparison. Simulated fish habitat parameters for both eutrophic and oligotrophic lakes near Duluth, Minnesota, are shown in Figs. 7 to 9, but only for eutrophic, lakes near Kansas City, Missouri and Austin, Texas, in Figs. 10 to 15 (There is a larger number of oligotrophic lakes in Minnesota than in southern states). Fish habitat is presented for shallow (H_{MAX} = 4.0 m), medium-depth (H_{MAX} = 13.0 m) and deep (H_{MAX} = 24.0 m) lakes, and for each fish guild (cold-water, cool-water, and warmwater species), respectively. The different fish guilds, lake types (both depth and trophic states), and geographic locations are highlighted by bold face words in the figure titles. In Figs. 7 to 15, three fish habitats are clearly identified by different graphic patterns: ***dark areas*** for uninhabitable space, ***areas with horizontal dashed lines*** for good-growth habitat and ***white spaces within each plot*** for restricted growth habitat.

The depth-time contours (Figs. 7–15) show variations of fish habitat during *both winter and summer*. The previous study (Stefan et. al, 1992) was for the open-water water season only and could not provide any information about fish habitat during the winter period. During the winter period, water temperatures are always less than the lower good-growth limit for all three fish guilds, therefore winter conditions cannot support any good-growth habitat (Figs. 7 to 15). Fish are killed when DO concentrations at all depths drop below the DO survival limit (Table 2). This typically occurs in shallow, eutrophic, ice-covered lakes of cold regions, e.g. Minnesota and Wisconsin. Oxygen depletion typically starts at the bottom of a lake and moves upward. When DO concentrations of less than the survival limit reach the ice-water interface and last more than 7 days (as shown e.g. Figs. 7a, 8a and 9a), "winterkill" of fish occurs. Winterkill in shallow eutrophic lakes occurs only when the ice cover on a lake lasts sufficiently long, e.g. 3 to 4 months (Greenbank, 1945; Hutchinson, 1957) (Figs. 7a, 8a, and 9a). During the ice-cover period there is no oxygen exchange (reaeration) between the atmosphere and the water, and photosynthetic oxygen production is usually small for lack of light. High sedimentary and biochemical oxygen demands in **eutrophic** lakes diminish DO concentration gradually over time to values below the DO survival limits for fish (2.5 or 3.0 mg/l) at all depths.

Even though lakes with different depths may have almost the same DO concentration before the ice cover forms (4°C isothermal conditions with more or less saturated DO), the total oxygen content available for winter oxygen demands is much smaller in a shallow lake (due to the smaller lake volume) than in medium-depth and deep lakes. Therefore winterkill occurs in shallow lakes but does not occur in medium-depth and deep **eutrophic** lakes (Figs. 7b, 7c, 8b, 8c, 9b, and 9c) and any of the oligotrophic lakes (Figs. 7d to 7f, 8d to 8f and 9d to 9f) near Duluth, Minnesota. Oligotrophic lakes have low sedimentary and biochemical oxygen demands and are therefore able to maintain higher DO levels for fish thus avoiding "winterkill".

In this study it is assumed that low DO is the only factor to control winterkill in lakes. Very low temperature, e.g. at or below 2°C, may cause mortality through osmoregulatory dysfunction (Johnson and Evans, 1996). For example, in shallow eutrophic lakes near Duluth, MN (Fig. 7a) and under a projected $2xCO_2$ climate scenario, low DO concentration could force fish into a region less than 2 m below the ice-water interface, where water temperature is between 0 to 2°C. This type of possible "winterkill" due to low temperatures is not examined in this study.

Under the projected $2xCO_2$ CCC climate scenario, low DO conditions and winterkill during the ice-cover period are projected **not to occur** in the lakes (Figs. 7 to 15). Under the $2xCO_2$ climate scenario the ice cover period is projected to be up to 89 days shorter, ice formation is delayed by as much as 40 days, and ice cover melts earlier by up to 67 days (Fang and Stefan, 1998). Surface reaeration and photosynthetic oxygen production raise DO levels in lakes without ice cover. Earlier ice melting (shorter ice cover period) stops a further decrease of DO concentrations preventing fish winterkill. This is a positive influence of climate warming on lake aquatic ecosystems.

Figure 7a (large shallow lakes near Duluth, MN) shows an interesting effect of climate warming: Fish winterkill under past climate conditions due to low DO is replaced by summerkill under a projected $2xCO_2$ CCC climate scenario due to high water temperature. In the summer, high water temperatures at all depths (not low DO concentrations) cause shallow, eutrophic lakes (large surface area only, Fig. 7a and 10a) and oligotrophic lakes (all sizes, Fig. 7d) to be uninhabitable by fish. In shallow lakes wind mixing is strong enough to mix the entire lake creating a more or less uniform high water temperature profile, which leaves no refuge for fish species.

Under $2xCO_2$ climate, thermal stratification starts earlier and sedimentary and water column (biochemical) oxygen demands are higher due to elevated water temperature. Hence dissolved oxygen concentrations decrease more rapidly over time and become depleted earlier. Lake volumes below the DO survival limit are therefore higher under a $2xCO_2$ climate scenario (Figs. 7 to 15 for all lake types at all three selected locations). Strength of stratification under a $2xCO_2$ climate scenario is also stronger and increases from large to small surface area lakes (Figs. 7a, 8a, and 9a) and increases from shallow to deep lakes (Figs. 7a to 7c).

In stratified lakes, high water temperatures from the water surface downward and low DO concentrations from the lake bottom upward are the controlling factors for fish habitat during the open-water season. When isolines of lethal temperature and insufficient DO intersect each other for more than seven days in Figs 7 to 15, a stratified lake is uninhabitable for fish. Such summer non-survival conditions occur for **cold-water fish species** in all lake types near Kansas City, MO, and Austin, TX, under both past and projected 2xCO_2 climate (Figs. 10 and 13). **Cool-water** (Figs. 8, 11, and 14) and **warmwater** (Figs. 9, 12, and 15) fish species can be present in any lake at all three selected locations under both past and projected 2xCO_2 climate scenarios, except in shallow lakes with winterkill under past climate conditions.

Some lakes have suitable fish habitat during both winter and summer periods under past climate conditions (1961-1979), but are projected to become uninhabitable in summer under the 2xCO_2 CCC climate scenario. That is a significant impact on fish habitat due to climate warming illustrated e.g. in Fig. 7d for cold-water fish species in shallow lakes near Duluth, MN, and in Figs.14a and 14b for cool-water fish species in shallow and medium-depth lakes near Austin, TX.

III.2. Projected Fish Survival and Good-Growth Parameters

Nine fish-habitat parameters defined in Table 3 (section II.2) were determined for 27 types of lakes and at four locations (Duluth and Minneapolis, MN, Kansas City, MO, and Austin, TX) for each of the three fish guilds and under past (1961-1979) climate and the projected 2xCO_2 CCC climate scenario (e.g. Tables 4 and 5), respectively. Differences of fish habitat parameters are given in a separate table (e.g. Table 6). The information given in Tables 4 to 17 is not only for eutrophic, lakes, which are predominant at most latitudes, but also for mesotrophic and oligotrophic lakes. The information given in the Tables quantifies fish habitat spaces shown in Figs. 7 to 15.

Tables 4 to 17 give the earliest (**NSB**) and latest (**NSE**) dates (calendar day) when either temperature or DO does not meet the survival limit over the entire depth of a lake. The presence or absence of a fish guild is measured by the parameter **NSL** (Table 3). Since fish can move from unfavorable T and DO conditions to locations with favorable ones, a limitation at only some depths is not considered fatal. Fish will be absent from a lake as a whole if **at all depths** there is either a temperature or a DO survival limitation. If that occurs, the length of the period of time during which conditions everywhere in the lake become unsuitable for fish because either temperature is too high or DO is too low, is called NSL. In this study, if NSL exceeds **seven (7) days**, survival of fish is considered impossible.

Since a year-round water quality simulation model was used, the starting and ending dates for uninhabitable conditions (NSB and NSE) were determined during both the ice-cover period and the open-water season. Values of NSB, NSE, and NSL for three fish guilds and under both climate scenarios are summarized in Tables 7 and 11 for nine shallow lakes near Duluth and Minneapolis, Minnesota, respectively. No fish winterkill was simulated to occur in deeper lakes in Minnesota and in any lake at Kansas City, MO, and Austin, TX, under both climate scenarios. Tables 4, 5, 8, 9, 12, 13, and 15, 16 show simulated nine fish habitat parameters during the **open-water season.** When fish non-survival conditions (NSL > 7) were simulated under either climate scenarios, fish good-growth parameters were meaningless and were not presented in the above tables.

III.2.1. Fish survival in northern lakes

Winterkill of all three fish guilds is simulated to occur in most of the shallow eutrophic and mesotrophic lakes near Duluth and Minneapolis, MN, under the present climate conditions (1961-1979) (Tables 7a and 11a). Insufficient DO conditions (winterkill) are projected to last from 11 to 80 days. This agrees with field experience by the MNDNR (Minnesota Department of Natural Resources). There is no winterkill in shallow oligotrophic lakes at both locations (Tables 7a and 11a). It is projected that *winterkill problems will disappear* from all shallow lakes near Duluth and Minneapolis, MN, under the projected 2xCO_2 CCC climate scenario (Tables 7b and 11b).

For cold-water fish species in shallow lakes near Duluth, MN, water temperatures during the summer are projected to be too high (Fig. 7) under the projected 2xCO_2 CCC climate scenario (Table 11b). Therefore cold-water fish species in shallow lakes near Duluth, MN, that are threatened by low DO during the winter under past climate conditions, will be threatened by high water temperatures during the summer under the projected 2xCO_2 climate scenario. This is a significant ecological change.

Suitable fish habitat (i.e. NSL = 0) is simulated for all three fish guilds in all lake types near Duluth, MN, *during the summer* under past climate conditions (Table 4). Near Minneapolis, MN, cold-water fish cannot survive in summer in the shallow lakes but can exist in most other deep and stratified lakes under past climate conditions (Table 8a). Under the 2xCO_2 CCC climate scenario, cold-water fish (Table 9a) have only a remote chance to survive in deep and strongly stratified mesotrophic and oligotrophic lakes near Minneapolis, MN. Summerkill due to high temperatures lasts less than two months under past climate but longer than 3 months under the projected 2xCO_2 climate scenario. There is no problem of survival during the summer for cool-water and warmwater fish in lakes of the Minneapolis area under present and projected 2x CO_2 climate scenarios (Tables 8b, 8b, 9b, and 9c).

Under the projected 2xCO_2 climate scenario, non-survival conditions during the summer are projected to develop in mesotrophic and oligotrophic *shallow lakes* for cold-water fish species (Table 5a and Fig. 16b), but not for cool- and warmwater fish species

(Tables 5b and 5c; Figs. 17b and 18b) at *Duluth, MN*. In a previous study with a projected GISS climate scenario and an open-water water quality model, there were sixteen lakes including all shallow lakes and some of the medium-depth and deep lakes, which were projected to have non-survival conditions in summer for the cold-water fish assemblage (Stefan et al. 1995b). Differences are due to the outputs of the CCC and GISS General Circulation Models. The inclusion of sediment-water heat exchange in the year-round water quality model makes simulated water temperatures lower (Fang and Stefan 1996) and increases the number of lakes with suitable fish habitat in summer under a 2xCO_2 CCC scenario.

III.2.2. Fish survival in southern lakes

As one expects, cold-water fish species are unable to survive in shallow and medium-depth lakes at southern latitudes, e.g. Kansas City, MO (Table 12a), and Austin, TX (15a), because water temperatures are too high. Non-survival conditions are typical, even in relatively deep lakes due to both high surface water temperatures and low bottom DO. Marginally, cold-water fish species may be able to be present in a few deep mesotrophic and oligotrophic lakes (see Tables 12a and 15a). Cool-water fish species can exist in all types of lakes near Kansas City, MO (Table 12b), and in medium-depth and deep lakes near Austin, TX, but not in some shallow lakes near Austin, Texas (Table 15b). Warmwater fish species do not have any problems to survive in any lakes near Kansas City, MO, or Austin, TX (Table 12c and 15c) under past (1961-1979) climate conditions.

Under the projected 2xCO_2 CCC climate scenario, *cold-water* fish species would theoretically have a chance of survival in deep, small, oligotrophic lakes (Table 13a). It is projected that there will be non-survival conditions for *cool-water* fish species in most shallow lakes near Kansas City, MO (Table 13b), and all shallow and medium-depth (H_{MAX} = 13 m) lakes near Austin, TX (Table 16b). There will be no problem for warmwater fish species to be present in all lakes near both Kansas City, MO, and Austin, TX, under the projected 2xCO_2 CCC climate scenario (Tables 13c and 16c).

III.2.3. Projected changes in fish survival in northern and southern lakes

Differences of fish survival and growth parameters between projected and past climate scenarios **(2xCO_2 – Past)** for each fish guild at the four selected locations were also determined and are presented in Tables 6, 10, 14, and 17. When differences of NSL are zero, fish habitat exists under both projected and present climate conditions. When differences of NSL are positive numbers, they indicate that climate warming is projected to constrain survival conditions. A significant positive impact of projected climate warming is on northern shallow lakes (e.g. Table 7 for Duluth, Table 11 for Minneapolis, MN), where fish winterkill is projected to disappear as long as summerkill may not develop. When non-survival conditions are simulated, good-growth parameters are meaningless and were not given in the above tables.

III.3. Dependence of Good-Growth Parameters on Lake Geometry and Trophic State

In order to examine the dependence of fish habitat parameters on lake characteristics further, good-growth parameters are presented graphically using lake geometry ratio on one axis and Secchi depth on the other. The lake geometry ratio $A_S^{0.25}/H_{MAX}$ is related to the strength of stratification in a lake (Gorham and Boyce, 1989). Fish parameters presented include good-growth length (GSL) and normalized good-growth habitat areas (GGHA) and volumes (GGHV) for all three fish guilds. Fish parameters are presented for 27 lake types at four selected locations (Duluth, MN, Boulder, CO, Charleston, WV, and Austin, TX) (Fig. 4), and under past (1961-1979) climate and the projected $2xCO_2$ climate scenario, respectively, to show variation of the dependence on geographic location and climate conditions. Note that, Minneapolis, MN and Kansas City, MO, are now replaced by Boulder, CO, and Charleston, WV, respectively, to cover regions from east to west of the contiguous U.S.

When non-survival conditions at all depths exist in a lake type either during summer or winter, good-growth parameters are meaningless, and the lake is presented by a special symbol. In Figs. 16 to 24, *unfilled* and *filled* diamonds present lakes with non-survival conditions at all depths over more than seven days during the *summe*r open-water season and the *winter* ice-cover period, respectively. Crosses (with a value attached) in Figs. 16 to 24 represent lakes with meaningful good-growth parameters but where contour lines can not be generated due to limitation of data. Changes of fish habitat parameters in response to climate warming are presented on separate graphs and using symbols defined in Table 18.

Simulated, time-averaged **good-growth lengths (GSL)** for cold-water fish are about five (150 days) and eight (240 days) months in stratified medium and deep lakes at Duluth, MN, and Charleston, WV, under past climate conditions (Fig. 16a). Climate warming is projected to *increase* GSL by up to 50 days in deep lakes due to an increase of the stratification period, but to *decrease* GSL by up to 32 days in medium-depth lakes due to the increase of water temperature (Figs. 16b and 16c).

Good-growth lengths for cool- and warmwater fish were simulated to be about 3 months (83-101 days) and less than 2 months (47-59 days) in medium-depth and deep lakes near Duluth, MN, under past climate conditions, respectively. GSL can last up to 8 months (240 days) in southern lakes (Fig. 17a and 18a) under past climate conditions. Climate warming is projected to *increase* GSL by up to 57 days for both cool- and warmwater fish (Figs. 17b, 17c, 18b, and 18c), but to decrease GSL by up to 22 days for cool-water fish in several deep eutrophic and mesotrophic lakes near Austin, TX. Good-growth period depends more strongly on lake geometry and less on trophic state, with some variation by location and climate scenario.

Normalized good-growth habitat areas (GGHA) for cold-water fish species (Fig. 19a) were predicted to be 43 (Duluth) to 162 (Austin) days in medium-depth and deep lakes under past climate conditions. This is equivalent to a GGHA from 9 to 1620 km^2 days. Normalized GGHA for cool-water fish species (Figs. 20a and 20b) is about 12 to 55 days *smaller* than that for cold-water fish, and 12-52 days *larger* than that for warmwater fish (Figs. 21a and 21b) under both past and projected climate scenarios. Normalized GGHAs for the three fish assemblages are on the same order as values estimated by Christie and Regier (1988) for 21 large north-temperate lakes. Normalized GGHAs for all fish assemblages are weakly dependent on lake trophic state but strongly dependent on lake geometry ratio for lakes at Duluth, MN, and Austin, TX, while strongly dependent on both parameters for lakes at Boulder, CO, and Charleston, WV (Fig. 91a and 20a). Normalized GGHA always decreases with stronger stratification (lower geometry ratio) in lakes.

Loss (-) and gain (+) of good-growth habitat areas for all 27 investigated types of lakes in northern (Duluth) and southern (Minneapolis) Minnesota following a doubling of atmospheric CO_2 were determined as a percentage of past values [(CCC – Past)/Past] (Fang et al., 1998). Climate warming is projected to increase good-growth habitat areas for cool-water and warmwater fish species in medium-depth and deep lakes in northern Minnesota, on the average by 50% and 115%, respectively. These positive changes for fish habitat are greater than those estimated by using water temperature and DO profiles simulated by the open-water water quality model (Stefan et al. 1995a). For cold-water fish species, good-growth habitat areas are projected to have small increases in small and medium (surface area) deep lakes (<18%) and a small decrease (< 8%) in other stratified lakes of northern Minnesota. Similar changes of GGHA for all three fish guilds due to climate warming are projected for southern Minnesota lakes, but their magnitudes are much smaller.

Normalized good-growth habitat volumes (GGHV) for *cold-water* fish species (Fig. 22a) were simulated to be on the average 370 and 670 meter-days in medium-depth and deep lakes at Duluth, MN, respectively. Normalized GGHV is up to 1436 meter-days in deep oligotrophic lake at Austin, TX, under past climate conditions (Fig. 22) (longer GSL over a year). GGHV is weakly dependent on both trophic state and geometry ratio. Under the projected $2xCO_2$ CCC climate scenario (Fig. 22b), those lakes with remaining cold-water fish habitat are projected to have an increase in GGHV due to climate warming (longer stratification period) except lakes in the south (near Austin, TX).

Normalized GGHV for *cool-water* fish species for medium-depth and deep lakes near Duluth, MN, under past (1961-1979) climate conditions is on the average 300 and 380 meter-days, respectively (Fig. 23a). The average GGHV is only 160 meter-days for *warmwater* fish guilds in those same lakes near Duluth, MN. Deeper stratified lakes have larger good-growth habitat volumes for cool- and warmwater fish than shallow, well-mixed lakes (Figs. 23 and 24). Normalized GGHV values for *cool-water* and *warmwater* fish assemblages are more strongly dependent on trophic state than geometry ratio (Figs. 23 and 24) under both past and projected climate scenarios for medium-depth and deep lakes. In shallow lakes, GGHV is independent of trophic state, but decreases with an increase of geometry ratio. Impacts of climate warming on GGHVs follow the same pattern as those for the GGHAs.

IV. Model Validation and Sensitivity Analysis

IV.1. Validation of Simulated Fish Habitat Against Observations

Fish habitats estimated from simulated "normal" daily water temperature and DO profiles for the **open-water season** were previously validated against fish observations by Hondzo and others (1995a). The validation can now be extended to fish habitats estimated from water temperature and DO profiles simulated by the year-round water quality model. Model predictions of suitable fish habitats were tested against fish observations for 2231 lakes in northern MN (Table 19a) and for 771 lakes in southern MN (Table 19b). Fish observation data were available in the Minnesota Lakes Fisheries Database (ERLD/MFLDB, 1990). The parameter used for model validation is the non-survival length (NSL). NSL is defined as the total number of days when either temperature or dissolved oxygen does not meet the fish presence criteria at all depths. NSL gives the length of both summer and winter periods of non-survival conditions at all depths or the length of time over a year that fish presence criteria are not met. When NSL for a fish guild in a lake is estimated to be more than 7 days, it is concluded that the fish guild is unable to exist in that type of lake.

If at least one representative fish of a particular fish assemblage in a particular type of lake is observed where the model predicts suitability of that lake type for fishes of that fish assemblage, agreement between model and observation can be claimed (agreement, A). Similarly if fishes are observed when the model simulates non-survival conditions at all depths over more than seven days, disagreement between model and observation is concluded (disagreement, D). If fishes of a certain fish assemblage were not observed in a lake (no data, ND), no conclusions can be drawn by comparison with model simulations (Stefan et al., 1995b).

Tables 19a and 19b show that model prediction of fish habitat agrees well with field observations for all fish guilds in all medium-depth (H_{MAX} = 13 m) and deep (H_{MAX} = 24 m) lakes in both northern and southern Minnesota. This agreement with observations is better than the previous validation (Stefan et al. 1995a) for the above lake types. For shallow lakes, there are only two and three types, which have suitable fish habitat that agrees with field observations. These are small and medium oligotrophic lakes in northern Minnesota and small mesotrophic and oligotrophic lakes in southern Minnesota. Non-survival conditions in summer were not projected in all shallow lakes (Tables 7 and 11). When the DO survival limits for three guilds were set at 2.5 and 3.0 mg/l (Table 2), winterkill was projected in all eutrophic and some mesotrophic shallow lakes (Tables 7 and 11), which is in disagreement with observations.

The reasons of disagreement between model and observation can be grouped in two broad categories (Hondzo and Stefan, 1996): "(1) omission of critical life processes which affect fish presence, but are not included in the simulation model, and (2) uncertainties in the fish database and the model predictions." Stefan and others (1995b) explained the above reasons in detail. They did not address uncertainty of the DO survival limit for fish winterkill, which will be discussed in the next section.

IV.2. Sensitivity of Winter Fish Habitat to DO Survival Limits

The generally accepted cause for winterkill of fish is oxygen depletion (suffocation) due to prolonged periods of snow/ice cover (Greenbank, 1945; Cooper and Washburn, 1949). Under low-temperature conditions "thresholds of many species of fresh-water fishes lie between 1.0 and 2.0 mg/l. However, some of the less tolerant species may require up to 3.0 mg/l or possible higher." (Moore 1942). Moore's findings confirm the conclusion of Thompson (1925) that, at low temperature, "dissolved oxygen concentration between zero and two parts per million will kill all kinds of fishes." Cooper and Washburn (1946) examined several Michigan lakes for winterkill, and found that tolerance thresholds of dissolved oxygen can be much lower than those found by Moore (1942) and Thompson (1925), e.g. 0.6 mg/l for largemouth bass and bluegills, 0.3 - 0.4 mg/l for yellow perch, mud pickerel, pumpkinseeds, pike, and chubsuckers, and 0.2-0.3 mg/l for bullheads and golden shiners. Data from previous studies are still inadequate to establish reliable tolerance limits of dissolved oxygen for fish winterkill (Greenbank, 1945).

Therefore the sensitivity of estimated fish habitats during the ice-cover period to DO survival limits was conducted. During the winter ice-cover period, DO survival criteria were set at 0.0, 0.5, 1.0 mg/l for three sensitivity tests, respectively. These limits were set for each of the three fish guilds during the winter and without change of the DO survival limits during the open water season. Fish survival parameters (NSB, NSE, and NSL) obtained from the sensitivity analysis with three different DO limits are shown in Tables 20a to 20f for shallow lakes near Duluth and Minneapolis, Minnesota, for all three fish guilds. Simulated fish habitats under the three winter DO survival limits were then compared with fish observations. Results are shown as agreement (A) or disagreement (D) between simulations and observations (Table 20g). When the DO survival limit during the winter was set at 0.0 mg/l (anoxic conditions), winterkill was projected to occur in **only two** types of lakes – small (0.2 km^2) and medium (1.7 km^2) shallow, eutrophic lakes in northern Minnesota, which disagrees with observations (Table 20g). Winterkill was not projected to occur in any shallow lakes in southern Minnesota, which agrees with observations. When the DO survival limits during the winter were set at 0.5 and 1.0 mg/l, winterkill was projected to occur in five types of lakes in northern Minnesota. They include small (0.2 km^2) eutrophic lakes, medium (1.7 km^2) and large (10.0 km^2) eutrophic and mesotrophic shallow lakes. Two types of lakes in southern Minnesota (Minneapolis), were projected to have winterkill when the DO survival limits were at 0.5 and 1.0 mg/l during the winter (Table 20g). Based on this sensitivity analysis and comparison with fish observations, one may expect that fish can tolerate lower DO concentrations than 2.5 and 3.0 mg/l without winterkill in ice-covered lakes.

V. PROJECTED FISH HABITAT IN THE CONTIGUOUS U.S.

Good-growth parameters have some dependence on lake geometry and trophic status, even though variations from location to location, from past to projected $2xCO_2$ climate scenarios, and from one fish guild to another, do exist (Figs. 16 to 24). In order to investigate the dependence of fish parameters on geographic location (e.g. latitude), four lake types were selected to illustrate the distribution of good-growth parameters over the contiguous U.S. These lake types comprise a large shallow lake (*Type 7,* A_S = 10 km^2, H_{MAX} = 4.0 m), a small shallow lake (*Type 1,* A_S = 0.2 km^2, H_{MAX} = 4.0 m), a medium-surface area and -depth lake (*Type 13*, A_S = 1.7 km^2, H_{MAX} = 13.0 m), and a medium deep lake (*Type 22,* A_S = 1.7 km^2, H_{MAX} = 24.0 m). Lake 7 has the highest geometry ratio (Fig. 1) and is polymictic, i.e. frequently well-mixed. Lake 22 has a very low geometry ratio (Fig. 1) and is a strongly stratified lake in summer. Both lakes 1 and 13 have weak stratification in summer, lake 1 is a polymictic lake and lake 13 is a dimictic or monomictic lake depending on location. These four types of lakes selected are eutrophic lakes. Another four oligotrophic lakes (*lake types 3, 9, 15, and 24*) with the same geometric characteristics were also selected to construct U.S. maps of good-growth parameters for comparison. The distribution of lake geometry ratios and Secchi depths for these eight lake types is graphically shown in Figure 1 (modified).

In Figs. 25 to 48, when non-survival conditions at all depths exist in a lake type, either during summer or winter, good-growth parameters are meaningless, and the lake is represented by a symbol defined in Table 18. Statistical results (maximum, minimum, mean and standard deviation from mean) of fish habitat values are also given with each figure. Statistics were calculated only from data for those lakes shown on the map to have good growth conditions. Some show only a very small number of lakes. The statistics are summarized in Tables 21 to 23. Maps for good-growth parameters (GSL, GGHA, and GGHV) are presented for the eight selected lake types identified above and for three fish guilds (cold-water, cool-water and warmwater). Fish habitat parameters simulated for three fish guilds are presented in figures labelled a, b, and c for comparison. Each figure shows results simulated under past (1961-1979) climate conditions (top), under the projected $2xCO_2$ CCC GCM climate scenario (middle), and differences between projected and past climate scenarios ($2xCO_2$ - PAST) (bottom), separately. The presentation starts with the most well-mixed lake types (Lakes 9 and 7) and progresses towards the most strongly stratified lake types (Lakes 24 and 22). A eutrophic (z_s = 1.2 m) and an oligotrophic (z_s = 4.5 m) lake are presented for each geometry ratio (see Fig. 1, modified).

V.1. Geographic Distribution of Lakes with Suitable Fish Habitat

Good-growth periods (GSL) for eight selected lakes at 209 locations in the contiguous U.S. are shown on maps in Figs. 25 to 32. These U.S. maps for good-growth length clearly show regions where suitable fish habitat for specific fish guilds exists. U.S. maps for good-growth habitat areas GGHA (Figs. 33 to 40) and volumes GGHV (Figs. 41 to 48) provide similar information about geographic distribution of lakes with suitable fish habitat.

In the most well-mixed lakes (types 9 and 7 with lake geometry ratio = 14.1) **cold-water** fish have suitable habitat only in locations near the Canadian border and along the west coast. Climate change is projected to wipe out those last habitats by summerkill due to elevated water temperatures (Figs. 25a and 26a). For **cool-water** fish the situation is very different. In those same lakes cool-water fish will do well anywhere in the contiguous U.S., except in states of the lower Mississippi River valley, where summerkills are common (Figs. 25b and 26b). Projected climate warming may lengthen the good-growth period from 100 days to 150 days in the northern states; but the region with summerkill may extend further north into MO, NE and IA. Trophic state has only a minor influence on these patterns, except that in eutrophic lakes in the north (MN, ND, WI). Winterkill of cool-water fish, as well as warmwater fish, in those shallow lakes is presently a threat; it is eliminated by projected climate change. **Warmwater** fish can presently exist in those same lakes anywhere in the contiguous U.S. (Fig. 25c and 26c). The good-growth season is presently only on the order of 50 days in the north-western and –central states (WA, OR, MO, ID, WY, ND, SD, MN); it may be lengthened to 100 days after climate change. In southern states the GSL is already 200 days; it may increase by no more than 40 days in these regions. The winterkill problems in northern states are projected to disappear under warmer climate (as for cool-water fish).

Good-growth periods in type 1 and 3 lakes (Figs. 27 and 28, geometry ratio = 5.3) are very similar to those in type 7 and 9 (Figs. 25 and 27, geometry ratio = 14.l). These lakes are still relatively well mixed. Patterns in Figures 25 and 26 closely resemble those in Figures 27 and 28 for the corresponding fish guilds (figures a, b, c), and therefore need no separate discussion, with two exception: (1) cold water fishes in the slightly less well-mixed lake type 1 (eutrophic) are also threatened by winterkill (oxygen depletion) and therefore benefit from climate warming; (2) The summerkill regions for cool-water fish are slightly larger at the lower lake geometry ratio.

For the next lower lake geometry ratio of 2.8 (lake types 13 and 15), the maps of fish habitat distributions (Figs. 29 and 30) are substantially different from those before. That is because lake types 13 and 15 are seasonally stratified lakes (dimictic or monomictic). The differences to polymictic lakes are as follows: **Cold-water** fish in those lakes find at present habitat as far south as parts of NV, UT, CO, KS, IO, OH, PA and north thereof. Climate warming will change that, except for a small fringe along the Canadian border and the West Coast, where the good-growth period for **cold-water** fishes will shorten roughly from 150 to 100 days (Figs. 29a and 30a). **Cool-water** fish presently find habitat in lake types 13 and 15 everywhere in the country. Climate warming will introduce summerkill of cool-water species in these lake types in the southeastern states (FL, TX, LA, MS, Al, GA, NC, SC). The good growth period will be lengthened by up to 50 days in the north and less (down to 0 days) at mid-latitudes of the contiguous U.S. (Figs. 29b and 30b). For warmwater fish there is hardly any difference to polymictic lakes. Trophic state does not have a significant influence on the above habitat distributions (Figs. 29c and 30c).

At the lowest lake geometry ratio of 1.5 (lake types 22 and 24) seasonal stratification is very strong, and this is reflected in the geographic fish habitat distribution as follows. Cold-water fish can presently find habitat in such lakes as far south as NM and northern TX, AK, TN and SC (Fig. 31a). Climate warming is projected to move that limit up to CO, KS, AK, TN, and VA. The good-growth period for cold-water fish in lake type 24, now as long as 200 to 250 days will be increased by 0 to 75 days (Fig. 31a). All of this information is, however, for oligotrophic lakes (type 24, a relatively rare occurrence). For the more common eutrophic lakes (type 22, Fig. 32) with strong seasonal stratification (geometry ratio = 1.5), the geographic distribution of fish habitat is very different from that for oligotrophic lakes (Fig. 31). Eutrophic lakes of type 22 show no suitable habitat for cold-water fish in the southeastern U.S. (Fig. 32a). Climate warming pushes suitable habitat to portions of the northernmost states of the contiguous U.S. and some of the west coast. Good-growth periods are reduced to 100 – 200 days for the most part. For cold-water fish, trophic state has little influence on fish habitat in these strongly stratified lakes (types 22 and 24, Figs. 31b and 32b). The main difference is the introduction of summerkill after climate warming in the southeastern states (LA, MS, Al, GA and FL). For warmwater fish the influence of trophic state is negligible (Figs. 31c and 32c).

V.2. Projected Length of the Good-Growth Period

In addition to the geographic distribution of lakes with suitable fish habitat, the number of locations (out of 209 investigated), at which different lake types could have suitable fish habitat, is also informative. Some of those numbers are as follows: Possible winterkill (*filled diamonds*) of cold-water and cool-water fish is projected to occur in shallow, small (Figs. 28a, 28b) and large (Figs. 26a, 26b) lakes at 18 and 30 (Table 24a) locations, respectively, in the contiguous U.S. under past climate conditions. These lakes are distributed along the northern border of the U.S. (MO, ND, MN, WI, MI, NY, NH, MA, and ME). The number of locations with winterkill of warmwater fish is slightly less than for cold- and cool-water fish (Table 23a, Fig. 26c and Fig. 28c). Under the projected $2xCO_2$ climate scenario winterkill is projected not to occur at these locations. This is a positive impact of climate warming on fish habitat.

U.S. maps for good-growth length clearly show regions where suitable fish habitat for specific fish guilds exists (Figs. 25 to 32). For example, in shallow small lakes (*type 1*) cold-water fish are projected to exist in 65 out of 209 locations, distributed around mid-latitudes and the west coast (Fig. 28a) under past climate conditions, and in only 8 locations (Table 24a) under the 2xCO_2 climate scenario. Climate warming is projected to reduce the number of locations with suitable fish habitat for cold-water fish by 17% for deep oligotrophic lakes and by 87% for small shallow lakes. The number of locations in the contiguous U.S. with fish habitat for cool- and warmwater guilds is projected to decrease by up to 35% and increase by up to 8%, respectively (Table 24a). The largest change in locations with suitable fish habitat occurs in shallow lakes, and the smallest one in deep stratified lakes. Due to thermal and DO stratification, suitable fish habitat is projected to occur at more locations in deeper lakes than in shallow lakes (Figs. 25 to 32).

Cool-water and warmwater fish are projected to exist in many locations and lake types at southern latitudes under both climate scenarios. Cold-water fish can only have a remote chance to find habitat in a few strong stratified lakes at those latitudes. Good-growth lengths for cold-water fish in shallow lakes last on the average about four moths (120 days), but more than seven moths (210 days) in deep stratified lakes (Table 21a and Figs. 25 to 32) under past (1961-1979) climate conditions. For cool-water and warmwater fish, good-growth lengths, although variable with lake types, last on average 142-170 (Table 22a) and 131-139 days (Table 23a), respectively. Climate warming due to doubling of atmospheric CO_2 is projected to increase GSL by up to 35% (Table 22b) and 39% (Table 23b) for cool-water and warmwater fish or expressed differently on average by 5-24 and 25-39 days (Tables 22b and 23b), respectively. Good-growth lengths for cold-water fish species are projected to change from –25% (decrease) to 29% (increase) (Table 21c) under the projected 2xCO_2 climate scenario.

Good-growth lengths (GSL) for *cold-water* fish decrease from north to south in the contiguous U.S., while GSL for cool-water and warmwater fish guilds increase from north to south (Figs. 25 to 32). GSL is higher for cool-water fish than for warmwater fish. Differences between good-growth lengths in eutrophic lakes (Figs. 26, 28, 30, and 32) and oligotrophic lakes (e.g. Figs. 25, 27, 29, and 31) are bigger in shallow lakes and for cold-water fish than in deeper lakes and for cool-water and warmwater fish under both climate scenarios. Variations (standard deviation, STD) of GSL from the mean are on the order 40 days (Table 21).

Impacts of climate warming on fish habitats are shown in the bottom map of each figure, which gives differences of fish parameters between projected and past climate scenarios. Three symbols defined in Table 18 are used to highlight different types of changes in fish habitat. Differences of good-growth lengths at those locations with suitable fish habitat under both climate scenarios are plotted as contour lines. The values of these differences give the increase or decrease of GSL after climate warming; they also show the dependence on geographic locations.

V.3. Projected Good-Growth Habitat Areas and Volumes

Good-growth habitat areas (GGHA) and volumes (GGHV) at 209 locations in the contiguous U.S. are shown in Figs. 33 to 40 and Figs. 41 to 48, respectively, for eight selected lake types. Good-growth habitat areas (GGHA) for cold-water, cool-water and warmwater fish are on average 88-122 days (Table 21a), 72-147 days (Table 22a), and 53-133 days (Table 23a) under past (1961-1979) climate conditions, respectively. GGHA for cold-water fish has smaller variations with lake depth (geometry) than GSL does (Table 21a and Figs. 33 to 40). Maximum and minimum GGHA occur in eutrophic and oligotrophic, deep lakes (Table 21), respectively. GGHA in a lake is always less than GSL in the same lake. Dividing GGHA by GSL, one gets the average percentage of total bottom area available for good-growth. For example, in deep stratified eutrophic lakes (*Type 22*), there is less than 40% (88/226, Table 21a) of total bottom area available to good-growth of cold-water fish. Actually available bottom area for good-growth varies day by day and season by season (Stefan et al., 1995a). GGHA in shallow lakes is just slightly smaller than GSL, which indicates that most of the bottom areas are available to good-growth.

Under the 2xCO_2 climate scenario, GGHA is projected to increase on average by 0-16% (Table 22c) and 14 to 26% (Table 23c) for cool-water and warmwater fish, respectively. For cold-water fish GGHA is projected to change from –10% (decrease) to 10% (increase) due to climate warming (Table 21c). GGHA is projected to be on the average 100 to173, 79 to 151, and 69 to 155 days (Tables 21b, 22b and 23b) for cold-water, cool-water and warmwater fish under the 2xCO_2 climate scenario, respectively.

Good-growth habitat volumes (GGHV) integrate volume with depth and time during the good-growth period and show large variation with depth of a lake. For example, GGHV in shallow, small lakes (*Type 1*) is 145 meter-days and 732 meter-days in medium (surface area) deep lakes (*Type 24*) for cold-water fish under past (1961-1979) climate conditions. GGHV values in deep lakes (Fig. 48) also show large variations from location to location in the contiguous U.S. and have standard deviations from 139 to 256 and 163 to 279 meter-days (Table 21a) under past and projected climate scenarios, respectively. Dividing GGHV by GSL and lake mean depth (volume/surface area), one gets the average percentage of total lake volume available for good-growth, which will be examined in a future study.

Distributions of normalized GGHA and GGHV with geographic location in the contiguous U.S. show very similar if not identical patterns on the maps for identical types of lakes and for identical fish guilds (Figs. 33 to 48). Random samples are Figs. 33a and 41a, Figs. 33b and 41b, and Figs. 33c and 41c for cool-water, cool-water and warmwater fish, respectively. Values for cool-water and warmwater fish generally increase from north to south. GGHA for cold-water fish does not show a clear pattern with latitude (Figs. 33 to 40). GGHA and GGHV are higher for cool-water than for warmwater fish species. Values of GGHA and GGHV in oligotrophic (e.g. Figs. 34 and 36) lakes are typically greater than in eutrophic lakes (e.g. Figs. 33 and 35) with the same geometric typically greater than in eutrophic lakes (e.g. Figs. 33 and 35) with the same geometric characteristics. Good-growth habitat areas and volumes can be used to estimate fish yields under past and projected climate scenarios by using regression equations developed by Christie and Regier (1988).

V.4 Statistics of Fish Habitat in Lakes of the Contiguous U.S.

Statistical results for the three good-growth habitat parameters GSL, GGHA and GGHV for **cold-water, cool-water and warmwater fish** in *27 lake types* are summarized in Tables 21, 22, and 23, respectively, including maximum and minimum values, means and standard deviations (STD). Tables 21a, 22a, and 23a give results simulated for past climate, and Tables 21b, 22b, and 23b for projected $2xCO_2$ climate scenario. Differences of habitat parameter values between projected and past climate scenarios are given in Tables 21c, 22c and 23c (Note that Table 21c does not give the differences of statistical results in Tables 21b and 21a because averages reported).

A decrease in good-growth parameter values occurs in most of the 27 lake types for **cold-water fish** (Table 21c). This is a strong indication that climate warming due to doubling of atmospheric CO_2 develops unfavorable environmental (thermal and DO) conditions for cold-water fish. The number of locations used to develop the statistical results in Tables 21a, 21b, and 21c is given in Table 24a and Fig. 49a (bottom). The number of locations (out of 209 investigated) in the contiguous U.S., where lakes experience winterkill, summerkill or where they have suitable habitat year round, are given in Fig. 49a for different lake types and for past (left) and projected $2xCO_2$ (right) climate scenarios and listed in Table 24a. For example, shallow lakes at up to 191 and 205 locations are projected to have summerkill for **cold-water fish** under past (1962-1979) and the projected $2xCO_2$ climate scenarios, respectively. Up to 203 locations of 209 investigated have suitable cold-water fish habitat in deep oligotrophic lakes. Climate warming is projected to reduce that number of locations by up to 94 or 45% (case C in Table 24b). Reductions due to climate warming in the number of locations with year-round cold-water fish habitat are on average 29 (14% of 209 investigated), 90 (43%), and 65 (31%) locations (Case C in Table 24b) for shallow, medium-depth, and deep lakes, respectively. At up to 30 (14%) locations at northern latitudes (e.g. Duluth, MN, in Fig. 4), shallow eutrophic lakes are projected to experience a shift from winterkill to summerkill (Case A in Table 24b). Only small and medium-size, eutrophic shallow lakes are projected to show a shift from winterkill to suitable fish habitat year round at 3 or 4 (< 2%) locations (Case B in Table 24b). That is the only projected positive impact of climate warming on **cold-water fish**.

Under past climate conditions lakes at almost all locations (209) have suitable simulated **cool-water** fish habitat in medium-depth and deep lakes (Fig. 49b). Under a projected $2xCO_2$ climate scenario, shallow lakes at up to 96 locations (46% of 209 studied) in the southeastern states are projected to have summerkill of **cool-water** fish, compared to 36 (17%) locations under present climate conditions.

Climate warming is projected to reduce the number of locations, where lakes have suitable **cool-water fish** habitat, by up to 62 (30%) out of 209 locations investigated (Table 24b). Average reductions are 56 (27% of 209 investigated), 42 (20%), and 7 (3%) locations for shallow (4m), medium-depth (13m), and deep lakes (24m), respectively. The strongest influence of climate warming is projected to occur in shallow lakes. For example, at up to 30 locations at northern latitudes (e.g. Duluth, MN, in Fig. 8a), shallow eutrophic lakes are projected to experience a shift from winterkill to suitable fish habitat year round. Shallow lakes at up to 62 locations (Table 24b and Fig. 49b) mostly at southern latitudes are also projected to lose the **cool-water fish** habitat to summerkill under a projected 2xCO2 climate scenario (Table 24b and Fig. 49b). A shift from winterkill to summerkill (case A in Table 18) with climate change is not projected to occur at any locations (Case A is projected to occur only for cold-water fish, but not for cool-water and warmwater fish).

Figs. 50a, 50b, and 50c show the geographic distribution of the number of lake types (maximum 27 types) with suitable **cold-water, cool-water, and warmwater** fish habitat, respectively, simulated at 209 locations (dots) in the contiguous U.S. under past (top) and projected 2xCO_2 (bottom) climate scenarios. Under past climate conditions (top), there are only a few locations on the west-coast or at high elevation to support **cold-water** fish in **all** lake types (Fig. 50a). From 9 to 18 deep or medium-depth lake types can support cold-water fish at northern latitudes of the contiguous U.S., while most of the shallow lakes experience either winterkill or summerkill. Under a projected 2xCO_2 climate scenario, fewer lake types are projected to support cold-water fish at northern latitudes of the contiguous U.S. Regions where no lakes can support cold-water fish extend significantly further north under a 2xCO_2 climate scenario. The severe impact of climate warming on cold-water fish in small lakes (up to 10 km^2 surface area) in the contiguous U.S. is clearly shown in Fig. 50a.

Fig. 50b shows the geographic distribution of the number of lake types (maximum = 27 types) with suitable fish habitat simulated at 209 locations (dots) in the contiguous U.S. under past and projected climate scenarios. Under past climate conditions, only 21 to 24 lake types support cool-water fish at most northern latitudes of the contiguous U.S., because about 3 to 6 eutrophic and/or mesotrophic, shallow lake types are projected to have winterkill. Some medium-depth lakes and all shallow lakes (Fang et al., 1998a) around Texas, Louisiana, southern Arkansas, Mississippi, and Alabama, do not support cool-water fish under past climate conditions. Under a projected 2xCO_2 climate scenario, all lakes at northern latitudes can support cool-water fish because winterkill is projected to disappear from shallow lakes. Due to climate warming, fewer lake types are projected to support cool-water fish in most of the south-central and southeastern states. That is a severe impact of climate warming on cool-water fish in small lakes in the contiguous U.S.

The geographic distribution of the number of lake types (maximum 27 types) with simulated suitable **warmwater fish** habitat at 209 locations (dots) in the contiguous U.S. under past and projected climate scenarios is given in Fig. 50c. Under past climate conditions, shallow eutrophic and/or mesotrophic lakes are projected to experience winterkill at up to 30 locations in northern latitudes (e.g. Duluth, MN, Fig. 9a). With elimination of winterkill due to climate warming, all lake types are projected to support warmwater fish under a projected 2xCO_2 climate scenario. Therefore all lakes at southern latitudes of the contiguous U.S. can support warmwater fish habitat under both past and projected 2xCO_2 climate scenarios.

VI. SUMMARY AND CONCLUSIONS

Projected climate warming is expected to change aquatic/hydrologic systems most strongly in cold regions. This study is concerned with climate change effects on lakes, especially small lakes with surface areas up to 10 km^2 and depths up to 24 m in the northern and cold regions of the contiguous United States. We have chosen lake parameters which are most directly influenced by climate and which in turn have much influence on aquatic lifeforms, water quality and water uses. The two main parameters studied herein are lake water temperature (T) and dissolved oxygen (DO) concentration. The effect of climate and projected climate warming on these two parameters was illustrated in Volumes 1 and 2 of this report. Fish habitat changes in lakes in response to water temperature and DO changes in lakes are analyzed in this Volume 3 of the report. The results are illustrated in numerous graphs and maps.

A verified, process-oriented, unsteady and one-dimensional (vertical) year-round lake water quality model (MINLAKE96) was used for temperature and DO simulations in twenty-seven (27) types of lakes. The lakes chosen differed by surface area (A_S), maximum depth (H_{MAX}), and Secchi depth (z_s, a common limnological measure of lake transparency). These three parameters are known to have a crucial influence on water temperatures and DO concentrations, and hence fish habitat in lakes. Lakes simulated were treated as having constant volume and long hydraulic residence times. To specify a future $2xCO_2$ climate scenario, monthly increments of climate parameters derived from the Canadian Climate Center (CCC) General Circulation Model (GCM) were applied to measured past climate conditions from 1961 to 1979 following a protocol proposed by the U.S. Environmental Protection Agency.

This report summarizes parameters that quantify fish habitat in different lakes in the contiguous U.S. under different climate scenarios. Water temperature and DO criteria for survival and good-growth of fish assemblages (cold-water, cool-water, and warmwater) are specified. Fish habitat in lakes, as constrained by simulated T and DO, were determined for past (1961-1979) climate conditions and the projected $2xCO_2$ climate scenario. Suitable fish habitat and possible non-survival conditions were quantified during both winter ice-cover period and summer open-water season. This study includes a validation of fish habitat simulations against fish observations in 3,002 Minnesota lakes. Simulations of fish habitat agree with fish observations in all medium-depth and deep lakes for all three fish guilds. There is some disagreement for shallow lakes.

Fish winterkill is simulated to occur in shallow, eutrophic and mesotrophic lakes of cold regions under past climate conditions and is projected to disappear under the $2xCO_2$ climate scenario due to shorter ice cover periods. Since the DO survival limit is not well defined, sensitivity of simulated winterkill to three DO survival limits (0.0, 0.5 and 1.0 mg/l) was analyzed. A DO limit of 0 mg/l for winterkill produced better agreement with fish observations than higher limits.

Simulated results in this report were presented in four formats. (1) Depth-time contours (Figs. 7 to 15) were used to identify fish habitat (*uninhabitable space, restricted growth and good growth habitats*) as a function of depth in selected lakes at three selected locations (Duluth, MN, Kansas City, MO, and Austin, TX). (2) Tables (4 to 17) give nine simulated good-growth and survival parameters for three fish guilds in all 27 types of the lakes studied and at four selected locations (Duluth and Minneapolis, MN, Kansas City, MO, and Austin, TX). (3) Plots that show dependence of good-growth parameters on lake geometry ratio ($A_S^{0.25}/H_{MAX}$) and Secchi depth (z_s, trophic status) at four selected locations (Duluth, MN, Boulder, CO, Charleston, WV, and Austin, TX). (4) U.S. maps for selected lakes that show the geographic distribution of good-growth parameters at 209 locations in the contiguous U.S. Differences of fish growth and survival parameters between projected and past climate scenarios were quantified and presented in the last three formats.

Simulated good-growth length (GSL), habitat areas (GGHA) and volumes (GGHV) show significant changes with climate warming, some of these changes have been summarized in Section V. U.S. maps for good-growth parameters (GSL, GGHA, and GGHV) clearly identify regions in the contiguous U.S. where suitable fish habitat for cold-water, cool-water and warmwater fish species exists in specific lake types under past (1961-1979) and projected 2xCO_2 climate scenarios (Figs. 24 to 48). Statistical results for the three good-growth habitat parameters GSL, GGHA and GGHV for cold-water, cool-water and warmwater fish in *27 lake types* are summarized in Tables 21, 22, and 23, respectively, including maximum and minimum values, means and standard deviations (STD). The following conclusions stand out among the many study results:

(1) Climate warming is projected to eliminate winterkill (due to low DO) in shallow, eutrophic lakes in the contiguous U.S.

(2) Simulated good-growth periods, good-growth habitat areas and volumes for all three fish species depend more strongly on lake geometry ratio ($A_s^{0.25}/H_{max}$), which is a measure of the strength of stratification in a lake, than on lake trophic state (Secchi depth).

(3) In seasonally stratified lakes, the good-growth period for all three fish guilds is larger when lake geometry ratio (the strength of stratification) is smaller.

(4) While winterkill in shallow, eutrophic lakes under past climate conditions is projected to disappear under a 2xCO_2 climate scenario, summerkill of <u>cold-water fish</u> in mesotrophic lakes due to elevated temperature is likely.

(5) Simulated good-growth periods for <u>cold-water fish</u> range from 3 to 12 months and decrease from northern to southern latitudes in the contiguous U.S. Climate warming is projected to shorten good-growth periods in most lakes, by up to 120 days.

(6) Climate warming is projected to reduce the geographic areas (number of locations), where lakes have suitable cold-water fish habitat, by up to 45%. Average reductions are 14%, 43%, and 31% for shallow (4m), medium-depth (13m), and deep (24m) lakes, respectively. Cold-water fish have the best chance to survive in deep stratified lakes near the northern border of the contiguous U.S.

(7) Summerkill under the projected 2xCO_2 climate scenario is a projected significant negative impact on cool-water fish in southern lakes of the contiguous U.S., where suitable habitat exists under present conditions.

(8) For cool-water fish, climate warming is projected to lengthen the good-growth period by up to 137 days in lakes in the north-central and northeastern states and to shorten it by up to 103 days in lakes of several south-central and southeastern states of the contiguous U.S. Projected increases (due to climate warming) of the good-growth period, the good growth habitat areas and volumes of cool-water fish in medium-depth lakes of the contiguous U.S. are on average 20%, 10% and 8%, respectively.

(9) Climate warming is projected to reduce the geographic areas (number of locations), where lakes have suitable cool-water fish habitat, by up to 30%. Average reductions are 27%, 20%, and 3% for shallow (4m), medium-depth (13m), and deep (24m) lakes, respectively.

(10) Cool-water fish can exist in many lakes of the contiguous U.S. Exceptions are shallow, eutrophic lakes in the north-central U.S. (winterkill) and in south-central U.S. e.g. Louisiana, part of Texas, south Arkansas and Alabama, parts of Georgia and Florid (summerkill). Summerkill in shallow lakes will expand significantly in south-central and southeastern states under a 2xCO_2 climate scenario.

(11) Good-growth periods for cool-water and warmwater fish increase in length from northern to southern latitudes in the contiguous U.S. This relationship with latitude is inverse to the one found for cold-water fish.

(12) No summerkill of warmwater fish, due to elevated temperature and/or dissolved oxygen deficiency, is projected to occur in any lake and at any location of the contiguous U.S. investigated under both climate scenarios. Under the projected 2xCO_2 climate scenario, the good-growth period for warmwater fishes extends from about 75 days at northern latitudes to an entire year (365 days) at southern latitudes.

(13) Climate warming is projected to have several positive effects on warmwater fish habitat in lakes of the contiguous U.S. For example, climate warming is projected to increase the good-growth period of warmwater fishes on average by 30 to 40 days in

lakes at *all* locations investigated, more in deeper than in shallow lakes and more at northern than at southern latitudes. The highest relative increase of habitat areas/volumes with climate warming is over 200% and occurs at northern latitudes. In several southeastern states good-growth habitat areas and volumes are projected to decrease by up to 30% from the past values, which is the only negative impact of climate warming on warmwater fish found in this study.

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Tables 1 through 24

Table 1. Morphometric characteristics of 27 lake types used in the continental-scale simulations.

Maximum Depth H_{MAX} (m)	Surface Area A_S (km^2)	Secchi Depth z_s (m)			Geometry Ratio $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$)
		1.2 [a]	2.5 [b]	4.5 [c]	
Shallow (4.0)	Small (0.2)	Lake 1	Lake 2	Lake 3	5.3
	Medium (1.7)	Lake 4	Lake 5	Lake 6	9.0
	Large (10.0)	Lake 7	Lake 8	Lake 9	14.1
Medium Depth (13.0)	Small (0.2)	Lake 10	Lake 11	Lake 12	1.6
	Medium (1.7)	Lake 13	Lake 14	Lake 15	2.8
	Large (10.0)	Lake 16	Lake 17	Lake 18	4.3
Deep (24.0)	Small (0.2)	Lake 19	Lake 20	Lake 21	0.9
	Medium (1.7)	Lake 22	Lake 23	Lake 24	1.5
	Large (10.0)	Lake 25	Lake 26	Lake 27	2.3

[a] – Eutrophic lakes, [b] – Mesotrophic lakes, [c] – Oligotrophic lakes.

Table 2. Thermal and dissolved oxygen criteria for fish (guild means and ranges for species within a guild, after Stefan et al., 1992a).

Guild	Lower good-growth temperature LGGT (°C)	Upper good-growth temperature UGGT (°C)	Upper lethal temperature LT (°C)	Optimum temperature OT (°C)	Dissolved Oxygen DO (mg/l)
Cold-water[1]					
Mean	9.0	18.5	23.4	15.3	3.0
Range	(6.4-11.8)	(15.5-21.2)	(22.1-26.6)	(11.5-18.7)	
Cool-water[2]					
Mean	16.3	28.2	30.4	25.1	3.0
Range	(13.2-18.2)	(27.7-28.8)	(28.0-32.3)	(24.0-25.7)	
Warmwater[3]					
Mean	19.7	32.3	34.5	29.2	2.5
Range	(17.7-22.5)	(31.3-34.7)	(32.3-36.0)	(27.0-32.0)	

[1] Cold-water fish species are brook trout, brown trout, chinook salmon, chum salmon, coho salmon, mountain whitefish, pink salmon, and rainbow trout.

[2] Cool-water species are black crappie, northern pike, sauger, walleye, white crappie, white sucker, and yellow perch.

[3] Warmwater fish species are bluegill, brown bullhead, carp, channel catfish, flathead catfish, freshwater drum, gizzard shad, golden shiner, green sunfish, largemouth bass, rock bass, smallmouth bass, smallmouth buffalo, and white bass.

Table 3. Thermal and dissolved oxygen limited habitat for the open water season.

In the definitions below, the depth at which dissolved oxygen (DO) equals the DO survival limit is taken to be the useful lake depth. Lake volumes (GGHV) below that depth are ignored.

Parameter	Description
NSB	Earliest Julian date when in the vertical lake profile either temperature or dissolved oxygen do not meet the fish presence criteria at all depths.
NSE	Latest Julian date when in the vertical lake profile either temperature or dissolved oxygen do not meet the fish presence criteria at all depths.
NSL	Total number of days when in the vertical lake profile either temperature or dissolved oxygen do not meet the fish presence criteria at all depths. Defines length of yearly period of no survival = length of time that fish presence criteria are not met = NSE – NSB
GSB	Earliest Julian date when simultaneously any value of temperature exceeds the lower good growth bound in the vertical temperature profile and dissolved oxygen exceeds the limit in the dissolved oxygen profile.
GSE	Latest Julian date when simultaneously any value of temperature exceeds the lower good growth bound in the vertical temperature profile and dissolved oxygen exceeds the limit in the dissolved oxygen profile.
GSL	Total number of days when simultaneously any value of temperature is between the lower and upper good growth bound in the vertical temperature profile and dissolved oxygen exceeds the limit in the dissolved oxygen profile = length of good growth season.
GZER	Total number of days when simultaneously the upper limit for good growth temperature and the dissolved oxygen survival limit are exceeded in the lake profile. This is the midsummer period of reduced growth potential, stress and possible death. It includes the NSL period.
$\sum \frac{A(z) * J_d}{A_S}$ (days)	Integration of lake bottom areas (GGHA) (m^2) over time (days) where and when (a) water temperatures are within the upper and lower good growth temperature limits and (b) dissolved oxygen is greater than the survival limit. Integration begins at the first exceedance of the lower growth limit and the dissolved oxygen survival limit. This is the summation of possible good-growth bottom areas (GGHA) over the growing season. The final value is divided by surface area A_S for normalization.
$\sum \frac{V(z) * J_d}{A_S}$ (m-days)	Integration of volumes (GGHV) (m^3) over time (days) where and when (a) water temperatures are within the upper and lower good growth temperature limits and (b) dissolved oxygen is greater than the survival limit. Integration begins at the first exceedance of the lower growth limit and the dissolved oxygen survival limit. This is the summation of possible good-growth volumes (GGHV) over the growing season. The final value is divided by surface area A_S for normalization.

Table 4a. **Cold-water** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Duluth, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	127	279	140	13	91	130
		mesotrophic	0	0	0	125	280	101	55	90	129
		oligotrophic	0	0	0	117	280	96	63	91	131
	MEDIUM (1.7)	eutrophic	0	0	0	126	279	118	36	92	111
		mesotrophic	0	0	0	125	279	98	57	90	111
		oligotrophic	0	0	0	119	279	95	62	91	112
	LARGE (10.0)	eutrophic	0	0	0	127	278	94	58	90	110
		mesotrophic	0	0	0	126	278	93	60	91	111
		oligotrophic	0	0	0	119	278	95	61	92	113
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	134	284	151	0	60	333
		mesotrophic	0	0	0	133	285	153	0	71	381
		oligotrophic	0	0	0	133	286	154	0	86	422
	MEDIUM (1.7)	eutrophic	0	0	0	134	283	150	0	91	376
		mesotrophic	0	0	0	133	283	151	0	93	377
		oligotrophic	0	0	0	134	283	150	0	93	364
	LARGE (10.0)	eutrophic	0	0	0	134	282	148	1	95	374
		mesotrophic	0	0	0	134	282	148	1	96	373
		oligotrophic	0	0	0	134	282	122	27	93	364
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	135	285	151	0	43	459
		mesotrophic	0	0	0	135	289	155	0	52	544
		oligotrophic	0	0	0	136	291	156	0	61	625
	MEDIUM (1.7)	eutrophic	0	0	0	136	289	154	0	80	650
		mesotrophic	0	0	0	136	289	154	0	88	699
		oligotrophic	0	0	0	137	290	154	0	93	720
	LARGE (10.0)	eutrophic	0	0	0	137	289	153	0	102	772
		mesotrophic	0	0	0	137	289	153	0	110	806
		oligotrophic	0	0	0	137	289	153	0	109	784

Table 4b. **Cool-water** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Duluth, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	154	251	98	0	78	125
		mesotrophic	0	0	0	155	251	97	0	93	136
		oligotrophic	0	0	0	155	251	97	0	96	139
	MEDIUM (1.7)	eutrophic	0	0	0	155	250	93	0	90	111
		mesotrophic	0	0	0	155	250	91	0	90	111
		oligotrophic	0	0	0	155	250	91	0	91	111
	LARGE (10.0)	eutrophic	0	0	0	155	249	89	0	89	109
		mesotrophic	0	0	0	155	249	89	0	89	109
		oligotrophic	0	0	0	155	249	89	0	89	109
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	155	253	99	0	37	214
		mesotrophic	0	0	0	155	253	99	0	50	286
		oligotrophic	0	0	0	155	255	101	0	65	357
	MEDIUM (1.7)	eutrophic	0	0	0.	155	253	98	0	62	274
		mesotrophic	0	0	0	156	253	96	0	69	304
		oligotrophic	0	0	0	157	253	95	0	79	337
	LARGE (10.0)	eutrophic	0	0	0	158	253	90	0	78	325
		mesotrophic	0	0	0	160	253	89	0	80	330
		oligotrophic	0	0	0	160	253	89	0	83	336
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	155	253	99	0	22	239
		mesotrophic	0	0	0	155	255	101	0	31	332
		oligotrophic	0	0	0	158	256	94	0	39	410
	MEDIUM (1.7)	eutrophic	0	0	0	157	253	92	0	38	318
		mesotrophic	0	0	0	158	254	91	0	42	351
		oligotrophic	0	0	0	166	255	89	0	51	422
	LARGE (10.0)	eutrophic	0	0	0	169	255	86	0	53	432
		mesotrophic	0	0	0	170	255	84	0	54	446
		oligotrophic	0	0	0	173	255	83	0	59	483

Table 4c. **Warmwater** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Duluth, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	175	233	59	0	40	66
		mesotrophic	0	0	0	175	233	59	0	53	80
		oligotrophic	0	0	0	175	233	59	0	57	82
	MEDIUM (1.7)	eutrophic	0	0	0	178	232	53	0	48	61
		mesotrophic	0	0	0	178	232	53	0	51	64
		oligotrophic	0	0	0	178	232	53	0	52	65
	LARGE (10.0)	eutrophic	0	0	0	178	232	48	0	47	58
		mesotrophic	0	0	0.	178	232	48	0	48	59
		oligotrophic	0	0	0	178	232	48	0	48	59
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	177	233	57	0	17	99
		mesotrophic	0	0	0	178	234	57	0	25	143
		oligotrophic	0	0	0	179	234	56	0	33	184
	MEDIUM (1.7)	eutrophic	0	0	0	178	233	56	0	27	123
		mesotrophic	0	0	0	179	233	55	0	33	146
		oligotrophic	0	0	0	180	233	54	0	39	173
	LARGE (10.0)	eutrophic	0	0	0	181	233	53	0	35	153
		mesotrophic	0	0	0	181	233	53	0	37	164
		oligotrophic	0	0	0	182	233	52	0	42	180
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	177	233	57	0	10	108
		mesotrophic	0	0	0	178	234	57	0	15	158
		oligotrophic	0	0	0	180	234	55	0	19	207
	MEDIUM (1.7)	eutrophic	0	0	0	178	233	56	0	17	140
		mesotrophic	0	0	0	180	233	54	0	19	162
		oligotrophic	0	0	0	182	234	53	0	25	209
	LARGE (10.0)	eutrophic	0	0	0	183	233	50	0	20	171
		mesotrophic	0	0	0	186	233	48	0	22	184
		oligotrophic	0	0	0	187	233	47	0	26	213

Table 5a. **Cold-water** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Duluth, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	199	218	4	101	290	114	76	81	116
		mesotrophic	187	232	45	-	-	-	-	-	-
		oligotrophic	178	234	56	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	199	218	3	101	288	107	81	79	94
		mesotrophic	187	232	41	-	-	-	-	-	-
		oligotrophic	178	233	54	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	188	227	36	-	-	-	-	-	-
		mesotrophic	179	233	52	-	-	-	-	-	-
		oligotrophic	178	233	54	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	103	297	138	57	60	330
		mesotrophic	0	0	0	103	297	151	44	70	367
		oligotrophic	0	0	0	103	298	179	17	84	404
	MEDIUM (1.7)	eutrophic	0	0	0	103	296	129	65	89	358
		mesotrophic	0	0	0	103	296	131	63	88	352
		oligotrophic	0	0	0	103	296	137	57	87	338
	LARGE (10.0)	eutrophic	0	0	0	104	295	116	76	89	350
		mesotrophic	0	0	0	104	295	119	73	89	347
		oligotrophic	0	0	0	104	295	116	76	86	335
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	106	298	162	31	43	459
		mesotrophic	0	0	0	106	300	195	0	59	606
		oligotrophic	0	0	0	106	302	197	0	72	714
	MEDIUM (1.7)	eutrophic	0	0	0	107	301	155	40	81	646
		mesotrophic	0	0	0	106	301	196	0	92	719
		oligotrophic	0	0	0	107	301	195	0	109	797
	LARGE (10.0)	eutrophic	0	0	0	108	301	143	51	98	730
		mesotrophic	0	0	0	109	301	168	25	105	766
		oligotrophic	0	0	0	109	301	193	0	112	780

Table 5b. **Cool-water** fish survival and growth parameters in lakes for projected **2xCO_2 CCC** climate scenario at **Duluth, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	135	264	130	0	104	168
		mesotrophic	0	0	0	135	265	131	0	126	186
		oligotrophic	0	0	0	135	265	131	0	130	187
	MEDIUM (1.7)	eutrophic	0	0	0	136	264	129	0	126	157
		mesotrophic	0	0	0.	136	264	129	0	129	158
		oligotrophic	0	0	0	136	264	129	0	129	158
	LARGE (10.0)	eutrophic	0	0	0	136	264	129	0	129	158
		mesotrophic	0	0	0	136	264	129	0	129	158
		oligotrophic	0	0	0	136	264	129	0	129	158
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	136	266	131	0	51	297
		mesotrophic	0	0	0	136	268	133	0	73	410
		oligotrophic	0	0	0	136	270	135	0	96	518
	MEDIUM (1.7)	eutrophic	0	0	0	136	267	132	0	84	373
		mesotrophic	0	0	0	137	267	131	0	98	427
		oligotrophic	0	0	0	137	268	132	0	114	483
	LARGE (10.0)	eutrophic	0	0	0	137	267	131	0	109	464
		mesotrophic	0	0	0	137	267	131	0	117	489
		oligotrophic	0	0	0	138	267	130	0	125	507
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	136	267	132	0	32	353
		mesotrophic	0	0	0	136	270	135	0	47	505
		oligotrophic	0	0	0	137	272	136	0	61	648
	MEDIUM (1.7)	eutrophic	0	0	0	137	268	132	0	58	486
		mesotrophic	0	0	0	137	270	134	0	69	573
		oligotrophic	0	0	0	138	271	134	0	84	690
	LARGE (10.0)	eutrophic	0	0	0	138	271	134	0	82	674
		mesotrophic	0	0	0	138	271	133	0	91	743
		oligotrophic	0	0	0	139	272	132	0	104	823

Table 5c. **Warmwater** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Duluth**, **MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	146	253	104	0	76	125
		mesotrophic	0	0	0	148	253	104	0	96	143
		oligotrophic	0	0	0	148	253	104	0	101	146
	MEDIUM (1.7)	eutrophic	0	0	0	154	251	98	0	92	116
		mesotrophic	0	0	0	154	251	97	0	96	118
		oligotrophic	0	0	0	154	251	97	0	96	118
	LARGE (10.0)	eutrophic	0	0	0	155	250	94	0	93	115
		mesotrophic	0	0	0	155	250	94	0	94	115
		oligotrophic	0	0	0	155	250	94	0	94	115
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	148	255	105	0	35	206
		mesotrophic	0	0	0	154	255	102	0	51	290
		oligotrophic	0	0	0	155	256	102	0	67	367
	MEDIUM (1.7)	eutrophic	0	0	0	154	255	102	0	56	251
		mesotrophic	0	0	0	155	255	101	0	68	299
		oligotrophic	0	0	0	155	255	101	0	81	348
	LARGE (10.0)	eutrophic	0	0	0	155	255	101	0	75	325
		mesotrophic	0	0	0	155	255	101	0	82	350
		oligotrophic	0	0	0	155	255	101	0	90	371
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	149	255	104	0	21	234
		mesotrophic	0	0	0	154	256	103	0	31	333
		oligotrophic	0	0	0	155	258	104	0	41	440
	MEDIUM (1.7)	eutrophic	0	0	0	155	255	101	0	36	305
		mesotrophic	0	0	0	155	255	101	0	43	359
		oligotrophic	0	0	0	155	256	102	0	54	451
	LARGE (10.0)	eutrophic	0	0	0	156	255	99	0	51	421
		mesotrophic	0	0	0	156	256	99	0	55	456
		oligotrophic	0	0	0	158	256	96	0	61	503

Table 6a. **Differences** of **cold-water** fish survival and growth parameters between projected and past climate scenarios (**2xCO_2-PAST**) for lakes at **Duluth, MN**.

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	4	-26	11	-26	63	-10	-14
		mesotrophic	45	-	-	-	-	-	-
		oligotrophic	56	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	3	-25	9	-11	45	-13	-17
		mesotrophic	41	-	-	-	-	-	-
		oligotrophic	54	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	36	-	-	-	-	-	-
		mesotrophic	52	-	-	-	-	-	-
		oligotrophic	54	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	-31	13	-13	57	0	-3
		mesotrophic	0	-30	12	-2	44	-1	-14
		oligotrophic	0	-30	12	25	17	-2	-18
	MEDIUM (1.7)	eutrophic	0	-31	13	-21	65	-2	-18
		mesotrophic	0	-30	13	-20	63	-5	-25
		oligotrophic	0	-31	13	-13	57	-6	-26
	LARGE (10.0)	eutrophic	0	-30	13	-32	75	-6	-24
		mesotrophic	0	-30	13	-29	72	-7	-26
		oligotrophic	0	-30	13	-6	49	-7	-29
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-29	13	11	31	0	0
		mesotrophic	0	-29	11	40	0	7	62
		oligotrophic	0	-30	11	41	0	11	89
	MEDIUM (1.7)	eutrophic	0	-29	12	1	40	1	-4
		mesotrophic	0	-30	12	42	0	4	20
		oligotrophic	0	-30	11	41	0	16	77
	LARGE (10.0)	eutrophic	0	-29	12	-10	51	-4	-42
		mesotrophic	0	-28	12	15	25	-5	-40
		oligotrophic	0	-28	12	40	0	3	-4

Table 6b. **Differences** of **cool-water** fish survival and growth parameters between projected and past climate scenarios (**$2xCO_2$-PAST**) for lakes at **Duluth, MN**.

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	-19	13	32	0	26	43
		mesotrophic	0	-20	14	34	0	33	50
		oligotrophic	0	-20	14	34	0	34	48
	MEDIUM (1.7)	eutrophic	0	-19	14	36	0	36	46
		mesotrophic	0	-19	14	38	0	39	47
		oligotrophic	0	-19	14	38	0	38	47
	LARGE (10.0)	eutrophic	0	-19	15	40	0	40	49
		mesotrophic	0	-19	15	40	0	40	49
		oligotrophic	0	-19	15	40	0	40	49
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	-19	13	32	0	14	83
		mesotrophic	0	-19	15	34	0	23	124
		oligotrophic	0	-19	15	34	0	31	161
	MEDIUM (1.7)	eutrophic	0	-19	14	34	0	22	99
		mesotrophic	0	-19	14	35	0	29	123
		oligotrophic	0	-20	15	37	0	35	146
	LARGE (10.0)	eutrophic	0	-21	14	41	0	31	139
		mesotrophic	0	-23	14	42	0	37	159
		oligotrophic	0	-22	14	41	0	42	171
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-19	14	33	0	10	114
		mesotrophic	0	-19	15	34	0	16	173
		oligotrophic	0	-21	16	42	0	22	238
	MEDIUM (1.7)	eutrophic	0	-20	15	40	0	20	168
		mesotrophic	0	-21	16	43	0	27	222
		oligotrophic	0	-28	16	45	0	33	268
	LARGE (10.0)	eutrophic	0	-31	16	48	0	29	242
		mesotrophic	0	-32	16	49	0	37	297
		oligotrophic	0	-34	17	49	0	45	340

Table 6c. **Differences** of **warmwater** fish survival and growth parameters between projected and past climate scenarios (**2xCO_2-PAST**) for lakes at **Duluth, MN**.

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	-29	20	45	0	36	59
		mesotrophic	0	-27	20	45	0	43	63
		oligotrophic	0	-27	20	45	0	44	64
	MEDIUM (1.7)	eutrophic	0	-24	19	45	0	44	55
		mesotrophic	0	-24	19	44	0	45	54
		oligotrophic	0	-24	19	44	0	44	53
	LARGE (10.0)	eutrophic	0	-23	18	46	0	46	57
		mesotrophic	0	-23	18	46	0	46	56
		oligotrophic	0	-23	18	46	0	46	56
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	-29	22	48	0	18	107
		mesotrophic	0	-24	21	45	0	26	147
		oligotrophic	0	-24	22	46	0	34	183
	MEDIUM (1.7)	eutrophic	0	-24	22	46	0	29	128
		mesotrophic	0	-24	22	46	0	35	153
		oligotrophic	0	-25	22	47	0	42	175
	LARGE (10.0)	eutrophic	0	-26	22	48	0	40	172
		mesotrophic	0	-26	22	48	0	45	186
		oligotrophic	0	-27	22	49	0	48	191
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-28	22	47	0	11	126
		mesotrophic	0	-24	22	46	0	16	175
		oligotrophic	0	-25	24	49	0	22	233
	MEDIUM (1.7)	eutrophic	0	-23	22	45	0	19	165
		mesotrophic	0	-25	22	47	0	24	197
		oligotrophic	0	-27	22	49	0	29	242
	LARGE (10.0)	eutrophic	0	-27	22	49	0	31	250
		mesotrophic	0	-30	23	51	0	33	272
		oligotrophic	0	-29	23	49	0	35	290

Table 7a. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under **past** climate conditions (1961-1979) at **Duluth, MN,** *when winter DO survival limit was set at 3.0 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	0	0	0	27	94	68
		mesotrophic	0	0	0	58	101	43
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	17	95	79
		mesotrophic	0	0	0	42	104	63
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	16	95	80
		mesotrophic	0	0	0	42	104	63
		oligotrophic	0	0	0	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	27	94	68
		mesotrophic	0	0	0	58	101	43
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	17	95	79
		mesotrophic	0	0	0	42	104	63
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	16	95	80
		mesotrophic	0	0	0	42	104	63
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	30	92	63
		mesotrophic	0	0	0	63	99	37
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	20	93	74
		mesotrophic	0	0	0	46	102	57
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	18	93	76
		mesotrophic	0	0	0	46	102	57
		oligotrophic	0	0	0	0	0	0

Table 7b. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under a **projected 2xCO_2 climate scenario (CCC GCM)** at **Duluth, MN,** *when winter DO limit was set at 3.0 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	189	218	4	0	0	0
		mesotrophic	187	232	45	0	0	0
		oligotrophic	178	234	56	0	0	0
	MEDIUM (1.7)	eutrophic	199	218	3	0	0	0
		mesotrophic	187	232	41	0	0	0
		oligotrophic	178	233	54	0	0	0
	LARGE (10.0)	eutrophic	188	227	36	0	0	0
		mesotrophic	179	233	52	0	0	0
		oligotrophic	178	233	54	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0

Table 8a. **Cold-water** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Minneapolis, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	199	207	4	107	295	116	73	79	115
		mesotrophic	186	220	34	-	-	-	-	-	-
		oligotrophic	178	233	54	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	199	208	5	106	294	93	96	80	97
		mesotrophic	181	219	37	-	-	-	-	-	-
		oligotrophic	178	230	46	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	180	219	31	-	-	-	-	-	-
		mesotrophic	179	221	40	-	-	-	-	-	-
		oligotrophic	179	221	42	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	116	301	144	42	55	302
		mesotrophic	0	0	0	115	301	173	14	65	343
		oligotrophic	0	0	0	115	301	187	0	81	391
	MEDIUM (1.7)	eutrophic	0	0	0	115	300	131	55	81	330
		mesotrophic	0	0	0	115	300	133	53	82	329
		oligotrophic	0	0	0	115	300	133	53	84	331
	LARGE (10.0)	eutrophic	0	0	0	116	298	107	76	83	328
		mesotrophic	0	0	0	116	298	110	73	84	328
		oligotrophic	0	0	0	116	298	105	78	82	322
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	116	301	186	0	39	418
		mesotrophic	0	0	0	117	303	187	0	53	549
		oligotrophic	0	0	0	117	305	189	0	65	648
	MEDIUM (1.7)	eutrophic	0	0	0	117	303	184	3	72	577
		mesotrophic	0	0	0	117	303	187	0	83	656
		oligotrophic	0	0	0	118	305	188	0	97	726
	LARGE (10.0)	eutrophic	0	0	0	119	304	145	41	88	660
		mesotrophic	0	0	0	119	304	186	0	97	705
		oligotrophic	0	0	0	120	304	185	0	104	715

Table 8b. **Cool-water** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Minneapolis, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	136	264	129	0	106	170
		mesotrophic	0	0	0	136	264	129	0	127	184
		oligotrophic	0	0	0	136	264	129	0	129	185
	MEDIUM (1.7)	eutrophic	0	0	0	136	263	128	0	127	156
		mesotrophic	0	0	0	136	263	128	0	128	157
		oligotrophic	0	0	0	136	263	128	0	128	157
	LARGE (10.0)	eutrophic	0	0	0	136	263	128	0	128	157
		mesotrophic	0	0	0	136	263	128	0	128	157
		oligotrophic	0	0	0	136	263	128	0	128	157
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	136	265	130	0	52	299
		mesotrophic	0	0	0	137	266	130	0	72	403
		oligotrophic	0	0	0	137	269	133	0	93	504
	MEDIUM (1.7)	eutrophic	0	0	0	138	266	129	0	87	385
		mesotrophic	0	0	0	138	266	129	0	98	426
		oligotrophic	0	0	0	138	266	129	0	111	471
	LARGE (10.0)	eutrophic	0	0	0	139	266	128	0	112	469
		mesotrophic	0	0	0	139	266	128	0	117	483
		oligotrophic	0	0	0	139	266	128	0	122	496
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	137	266	130	0	33	357
		mesotrophic	0	0	0	137	269	133	0	45	486
		oligotrophic	0	0	0	138	271	134	0	58	619
	MEDIUM (1.7)	eutrophic	0	0	0	138	266	129	0	58	489
		mesotrophic	0	0	0	139	267	129	0	66	551
		oligotrophic	0	0	0	141	270	130	0	79	653
	LARGE (10.0)	eutrophic	0	0	0	142	270	127	0	81	666
		mesotrophic	0	0	0	145	270	126	0	89	721
		oligotrophic	0	0	0	145	270	126	0	97	776

Table 8c. **Warmwater** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Minneapolis, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	153	255	102	0	80	129
		mesotrophic	0	0	0	154	255	101	0	98	143
		oligotrophic	0	0	0	154	255	100	0	99	142
	MEDIUM (1.7)	eutrophic	0	0	0	154	252	99	0	97	120
		mesotrophic	0	0	0	154	252	99	0	98	120
		oligotrophic	0	0	0	154	251	98	0	98	120
	LARGE (10.0)	eutrophic	0	0	0	155	251	97	0	97	119
		mesotrophic	0	0	0	155	251	97	0	97	119
		oligotrophic	0	0	0	155	251	97	0	97	119
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	154	255	102	0	37	215
		mesotrophic	0	0	0	154	255	102	0	52	294
		oligotrophic	0	0	0	155	256	102	0	68	370
	MEDIUM (1.7)	eutrophic	0	0	0	155	255	101	0	62	278
		mesotrophic	0	0	0	155	255	101	0	72	315
		oligotrophic	0	0	0	155	255	101	0	83	358
	LARGE (10.0)	eutrophic	0	0	0	155	255	101	0	84	357
		mesotrophic	0	0	0	155	255	101	0	88	369
		oligotrophic	0	0	0	156	255	100	0	93	382
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	154	255	102	0	22	242
		mesotrophic	0	0	0	155	256	102	0	31	337
		oligotrophic	0	0	0	155	257	103	0	41	439
	MEDIUM (1.7)	eutrophic	0	0	0	155	255	101	0	40	333
		mesotrophic	0	0	0	155	255	101	0	45	374
		oligotrophic	0	0	0	156	256	101	0	55	460
	LARGE (10.0)	eutrophic	0	0	0	156	255	100	0	56	461
		mesotrophic	0	0	0	156	255	100	0	59	487
		oligotrophic	0	0	0	157	256	100	0	65	535

Table 9a. **Cold-water** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Minneapolis, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	176	247	71	-	-	-	-	-	-
		mesotrophic	157	251	93	-	-	-	-	-	-
		oligotrophic	155	252	97	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	175	248	73	-	-	-	-	-	-
		mesotrophic	156	251	95	-	-	-	-	-	-
		oligotrophic	155	252	97	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	156	250	94	-	-	-	-	-	-
		mesotrophic	155	251	96	-	-	-	-	-	-
		oligotrophic	155	251	96	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	190	234	44	-	-	-	-	-	-
		mesotrophic	202	242	40	-	-	-	-	-	-
		oligotrophic	244	244	0	96	310	168	47	76	364
	MEDIUM (1.7)	eutrophic	186	242	55	-	-	-	-	-	-
		mesotrophic	188	245	57	-	-	-	-	-	-
		oligotrophic	195	249	54	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	182	252	70	-	-	-	-	-	-
		mesotrophic	185	252	67	-	-	-	-	-	-
		oligotrophic	187	253	66	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	214	234	19	-	-	-	-	-	-
		mesotrophic	0	0	0	97	312	216	0	57	590
		oligotrophic	0	0	0	97	314	218	0	71	704
	MEDIUM (1.7)	eutrophic	202	234	32	-	-	-	-	-	-
		mesotrophic	0	0	0	98	313	160	56	85	658
		oligotrophic	0	0	0	99	313	215	0	106	763
	LARGE (10.0)	eutrophic	200	242	42	-	-	-	-	-	-
		mesotrophic	0	0	0	100	313	141	73	90	644
		oligotrophic	0	0	0	100	313	191	23	98	671

Table 9b. **Cool-water** fish survival and growth parameters in lakes for projected $2xCO_2$ **CCC** climate scenario at **Minneapolis, MN.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	107	277	164	2	102	162
		mesotrophic	0	0	0	107	277	153	13	117	169
		oligotrophic	0	0	0	107	277	120	46	115	165
	MEDIUM (1.7)	eutrophic	0	0	0	107	276	164	0	129	160
		mesotrophic	0	0	0	107	276	152	12	129	157
		oligotrophic	0	0	0	107	276	135	29	125	152
	LARGE (10.0)	eutrophic	0	0	0	107	276	157	6	137	167
		mesotrophic	0	0	0	107	276	148	15	137	166
		oligotrophic	0	0	0	107	276	138	25	136	166
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	115	279	165	0	52	300
		mesotrophic	0	0	0	116	280	165	0	70	393
		oligotrophic	0	0	0	116	281	166	0	91	484
	MEDIUM (1.7)	eutrophic	0	0	0	116	279	164	0	89	390
		mesotrophic	0	0	0	116	279	164	0	101	436
		oligotrophic	0	0	0	116	280	165	0	114	480
	LARGE (10.0)	eutrophic	0	0	0	116	279	164	0	121	513
		mesotrophic	0	0	0	116	279	164	0	130	541
		oligotrophic	0	0	0	116	279	164	0	137	554
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	116	279	164	0	34	369
		mesotrophic	0	0	0	116	281	166	0	49	520
		oligotrophic	0	0	0	116	283	168	0	62	650
	MEDIUM (1.7)	eutrophic	0	0	0	116	280	165	0	62	520
		mesotrophic	0	0	0	116	281	166	0	74	611
		oligotrophic	0	0	0	117	282	166	0	93	761
	LARGE (10.0)	eutrophic	0	0	0	117	282	166	0	94	772
		mesotrophic	0	0	0	119	282	164	0	107	863
		oligotrophic	0	0	0	120	282	162	0	125	980

Table 9c. **Warmwater** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Minneapolis**, MN.

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	134	264	131	0	100	163
		mesotrophic	0	0	0	134	264	131	0	125	185
		oligotrophic	0	0	0	134	265	132	0	131	189
	MEDIUM (1.7)	eutrophic	0	0	0	134	264	131	0	125	158
		mesotrophic	0	0	0	134	264	131	0	130	160
		oligotrophic	0	0	0	134	264	131	0	130	160
	LARGE (10.0)	eutrophic	0	0	0	135	264	130	0	129	159
		mesotrophic	0	0	0	135	264	130	0	130	159
		oligotrophic	0	0	0	135	264	130	0	130	159
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	134	266	133	0	49	283
		mesotrophic	0	0	0	134	270	137	0	70	396
		oligotrophic	0	0	0	136	271	136	0	93	507
	MEDIUM (1.7)	eutrophic	0	0	0	136	266	131	0	77	346
		mesotrophic	0	0	0	136	266	131	0	92	407
		oligotrophic	0	0	0	136	268	133	0	111	474
	LARGE (10.0)	eutrophic	0	0	0	136	266	131	0	103	442
		mesotrophic	0	0	0	136	266	131	0	112	474
		oligotrophic	0	0	0	136	266	131	0	122	502
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	134	269	134	0	30	331
		mesotrophic	0	0	0	134	271	137	0	45	482
		oligotrophic	0	0	0	136	272	137	0	59	625
	MEDIUM (1.7)	eutrophic	0	0	0	136	270	135	0	52	437
		mesotrophic	0	0	0	136	270	135	0	64	531
		oligotrophic	0	0	0	136	271	136	0	80	662
	LARGE (10.0)	eutrophic	0	0	0	137	271	135	0	75	619
		mesotrophic	0	0	0	137	271	135	0	85	694
		oligotrophic	0	0	0	138	271	134	0	98	788

Table 10a. **Differences** of **cold-water** fish survival and growth parameters between projected and past climate scenarios (**2xCO_2-PAST**) for lakes at **Minneapolis, MN.**

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	67	-	-	-	-	-	-
		mesotrophic	59	-	-	-	-	-	-
		oligotrophic	43	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	68	-	-	-	-	-	-
		mesotrophic	58	-	-	-	-	-	-
		oligotrophic	51	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	63	-	-	-	-	-	-
		mesotrophic	56	-	-	-	-	-	-
		oligotrophic	54	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	44	-	-	-	-	-	-
		mesotrophic	40	-	-	-	-	-	-
		oligotrophic	0	-19	9	-19	47	-5	-27
	MEDIUM (1.7)	eutrophic	55	-	-	-	-	-	-
		mesotrophic	57	-	-	-	-	-	-
		oligotrophic	54	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	70	-	-	-	-	-	-
		mesotrophic	67	-	-	-	-	-	-
		oligotrophic	66	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	19	-	-	-	-	-	-
		mesotrophic	0	-20	9	29	0	4	41
		oligotrophic	0	-20	9	29	0	6	56
	MEDIUM (1.7)	eutrophic	32	-	-	-	-	-	-
		mesotrophic	0	-19	10	-27	56	2	2
		oligotrophic	0	-19	8	27	0	9	37
	LARGE (10.0)	eutrophic	42	-	-	-	-	-	-
		mesotrophic	0	-19	9	-45	73	-7	-61
		oligotrophic	0	-20	9	6	23	-6	-44

Table 10b. **Differences** of **cool-water** fish survival and growth parameters between projected and past climate scenarios (**$2xCO_2$-PAST**) for lakes at **Minneapolis, MN.**

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	-29	13	35	2	-8	-14
		mesotrophic	0	-29	13	24	13	-8	-12
		oligotrophic	0	-29	13	-9	46	-14	-22
	MEDIUM (1.7)	eutrophic	0	-29	13	36	0	-10	-11
		mesotrophic	0	-29	13	24	12	-8	-11
		oligotrophic	0	-29	13	7	29	-12	-15
	LARGE (10.0)	eutrophic	0	-29	13	29	6	-8	-10
		mesotrophic	0	-29	13	20	15	-8	-10
		oligotrophic	0	-29	13	10	25	-13	-17
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	-21	14	35	0	1	-1
		mesotrophic	0	-21	14	35	0	-2	-13
		oligotrophic	0	-21	12	33	0	-5	-27
	MEDIUM (1.7)	eutrophic	0	-22	13	35	0	-5	-27
		mesotrophic	0	-22	13	35	0	-6	-26
		oligotrophic	0	-22	14	36	0	-8	-34
	LARGE (10.0)	eutrophic	0	-23	13	36	0	-6	-27
		mesotrophic	0	-23	13	36	0	-7	-29
		oligotrophic	0	-23	13	36	0	-7	-27
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-21	13	34	0	3	21
		mesotrophic	0	-21	12	33	0	4	41
		oligotrophic	0	-22	12	34	0	6	56
	MEDIUM (1.7)	eutrophic	0	-22	14	36	0	3	12
		mesotrophic	0	-23	14	37	0	2	2
		oligotrophic	0	-24	12	36	0	9	37
	LARGE (10.0)	eutrophic	0	-25	12	39	0	-4	-45
		mesotrophic	0	-26	12	38	0	-7	-61
		oligotrophic	0	-25	12	36	0	-6	-44

Table 10c. **Differences** of **warmwater** fish survival and growth parameters between projected and past climate scenarios (**$2xCO_2$-PAST**) for lakes at **Minneapolis, MN.**

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	$\frac{A(z)*Jd}{As}$ (day)	$\frac{V(z)*Jd}{As}$ (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	-19	9	29	0	20	34
		mesotrophic	0	-20	9	30	0	27	42
		oligotrophic	0	-20	10	32	0	32	47
	MEDIUM (1.7)	eutrophic	0	-20	12	32	0	28	38
		mesotrophic	0	-20	12	32	0	32	40
		oligotrophic	0	-20	13	33	0	32	40
	LARGE (10.0)	eutrophic	0	-20	13	33	0	32	40
		mesotrophic	0	-20	13	33	0	33	40
		oligotrophic	0	-20	13	33	0	33	40
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	-20	11	31	0	12	68
		mesotrophic	0	-20	15	35	0	18	102
		oligotrophic	0	-19	15	34	0	25	137
	MEDIUM (1.7)	eutrophic	0	-19	11	30	0	15	68
		mesotrophic	0	-19	11	30	0	20	92
		oligotrophic	0	-19	13	32	0	28	116
	LARGE (10.0)	eutrophic	0	-19	11	30	0	19	85
		mesotrophic	0	-19	11	30	0	24	105
		oligotrophic	0	-20	11	31	0	29	120
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-20	14	32	0	8	89
		mesotrophic	0	-21	15	35	0	14	145
		oligotrophic	0	-19	15	34	0	18	186
	MEDIUM (1.7)	eutrophic	0	-19	15	34	0	12	104
		mesotrophic	0	-19	15	34	0	19	157
		oligotrophic	0	-20	15	35	0	25	202
	LARGE (10.0)	eutrophic	0	-19	16	35	0	19	158
		mesotrophic	0	-19	16	35	0	26	207
		oligotrophic	0	-19	15	34	0	33	253

Table 11a. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under past climate conditions (1961-1979) at **Minneapolis, MN,** *when winter DO limit was set at 3.0 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	199	207	4	43	80	37
		mesotrophic	186	220	34	0	0	0
		oligotrophic	178	233	54	0	0	0
	MEDIUM (1.7)	eutrophic	199	208	5	32	82	51
		mesotrophic	182	219	37	63	83	21
		oligotrophic	178	230	46	0	0	0
	LARGE (10.0)	eutrophic	180	219	31	31	82	52
		mesotrophic	179	221	40	63	83	21
		oligotrophic	179	221	42	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	43	80	37
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	32	82	51
		mesotrophic	0	0	0	63	83	21
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	31	82	52
		mesotrophic	0	0	0	63	83	21
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	47	78	31
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	35	81	47
		mesotrophic	0	0	0	69	79	11
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	34	81	48
		mesotrophic	0	0	0	70	79	10
		oligotrophic	0	0	0	0	0	0

Table 11b. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under **a projected 2xCO2 climate scenario (CCC GCM)** at **Minneapolis,** MN, *when winter DO limit was set at 3.0 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	176	247	71	0	0	0
		mesotrophic	157	251	93	0	0	0
		oligotrophic	155	252	97	0	0	0
	MEDIUM (1.7)	eutrophic	175	248	93	0	0	0
		mesotrophic	156	251	95	0	0	0
		oligotrophic	155	252	97	0	0	0
	LARGE (10.0)	eutrophic	156	250	94	0	0	0
		mesotrophic	155	251	96	0	0	0
		oligotrophic	155	251	96	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0

Table 12a. **Cold-water** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Kansas City**, **MO.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	169	243	74	-	-	-	-	-	-
		mesotrophic	159	254	93	-	-	-	-	-	-
		oligotrophic	156	255	99	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	165	244	76	-	-	-	-	-	-
		mesotrophic	158	254	94	-	-	-	-	-	-
		oligotrophic	157	255	98	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	157	253	94	-	-	-	-	-	-
		mesotrophic	157	254	97	-	-	-	-	-	-
		oligotrophic	156	254	98	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	190	240	46	-	-	-	-	-	-
		mesotrophic	202	243	41	-	-	-	-	-	-
		oligotrophic	234	245	11	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	184	242	58.	-	-	-	-	-	-
		mesotrophic	188	243	55	-	-	-	-	-	-
		oligotrophic	194	246	52	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	181	251	70	-	-	-	-	-	-
		mesotrophic	183	252	69	-	-	-	-	-	-
		oligotrophic	183	254	71	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	206	242	35	-	-	-	-	-	-
		mesotrophic	0	0	0	91	325	235	0	62	634
		oligotrophic	0	0	0	91	328	238	0	81	788
	MEDIUM (1.7)	eutrophic	205	216	11	-	-	-	-	-	-
		mesotrophic	0	0	0	93	326	173	61	89	695
		oligotrophic	0	0	0	95	326	232	0	112	809
	LARGE (10.0)	eutrophic	201	237	31	-	-	-	-	-	-
		mesotrophic	0	0	0	96	326	150	81	99	710
		oligotrophic	0	0	0	96	326	195	36	105	726

Table 12b. **Cool-water** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Kansas City, MO.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	107	289	180	0	124	196
		mesotrophic	0	0	0	107	289	180	0	145	209
		oligotrophic	0	0	0	107	289	147	33	144	208
	MEDIUM (1.7)	eutrophic	0	0	0	107	288	174	0	151	185
		mesotrophic	0	0	0	107	288	174	0	151	184
		oligotrophic	0	0	0	107	288	152	22	148	182
	LARGE (10.0)	eutrophic	0	0	0	108	288	170	0	156	190
		mesotrophic	0	0	0	108	288	167	3	156	191
		oligotrophic	0	0	0	108	287	160	9	157	192
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	108	291	180	0	63	361
		mesotrophic	0	0	0	113	295	182	0	87	489
		oligotrophic	0	0	0	113	296	183	0	115	610
	MEDIUM (1.7)	eutrophic	0	0	0	113	291	177	0	108	473
		mesotrophic	0	0	0	113	291	177	0	122	527
		oligotrophic	0	0	0	114	291	174	0	138	579
	LARGE (10.0)	eutrophic	0	0	0	115	291	173	0	143	600
		mesotrophic	0	0	0	120	291	172	0	151	626
		oligotrophic	0	0	0	120	291	172	0	159	640
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	112	291	179	0	40	435
		mesotrophic	0	0	0	113	296	183	0	60	643
		oligotrophic	0	0	0	115	297	179	0	77	803
	MEDIUM (1.7)	eutrophic	0	0	0	115	295	177	0	76	631
		mesotrophic	0	0	0	120	295	176	0	88	728
		oligotrophic	0	0	0	121	296	176	0	112	915
	LARGE (10.0)	eutrophic	0	0	0	122	296	175	0	114	923
		mesotrophic	0	0	0	123	296	174	0	126	1010
		oligotrophic	0	0	0	123	296	174	0	147	1150

Table 12c. **Warmwater** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Kansas City, MO.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	127	277	150	0	114	186
		mesotrophic	0	0	0	127	277	150	0	142	208
		oligotrophic	0	0	0	127	277	150	0	147	213
	MEDIUM (1.7)	eutrophic	0	0	0	127	273	140	0	135	168
		mesotrophic	0	0	0	127	271	139	0	137	169
		oligotrophic	0	0	0	127	271	139	0	139	170
	LARGE (10.0)	eutrophic	0	0	0	130	266	133	0	133	163
		mesotrophic	0	0	0	130	266	133	0	133	163
		oligotrophic	0	0	0	130	266	133	0	132	162
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	127	277	149	0	55	318
		mesotrophic	0	0	0	130	278	147	0	77	438
		oligotrophic	0	0	0	135	278	144	0	103	557
	MEDIUM (1.7)	eutrophic	0	0	0	134	277	144	0	89	397
		mesotrophic	0	0	0	135	277	143	0	104	455
		oligotrophic	0	0	0	135	277	143	0	122	519
	LARGE (10.0)	eutrophic	0	0	0	135	277	143	0	117	500
		mesotrophic	0	0	0	135	276	142	0	125	523
		oligotrophic	0	0	0	136	276	141	0	133	545
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	127	277	149	0	34	369
		mesotrophic	0	0	0	130	278	146	0	49	533
		oligotrophic	0	0	0	135	279	145	0	65	691
	MEDIUM (1.7)	eutrophic	0	0	0	135	277	143	0	60	501
		mesotrophic	0	0	0	135	277	143	0	70	585
		oligotrophic	0	0	0	135	278	144	0	88	722
	LARGE (10.0)	eutrophic	0	0	0	136	278	143	0	86	705
		mesotrophic	0	0	0	137	278	142	0	94	767
		oligotrophic	0	0	0	137	278	142	0	107	856

Table 13a. **Cold-water** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Kansas City**, **MO.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	150	259	106	-	-	-	-	-	-
		mesotrophic	138	264	126	-	-	-	-	-	-
		oligotrophic	130	271	138	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	144	262	111	-	-	-	-	-	-
		mesotrophic	137	263	126	-	-	-	-	-	-
		oligotrophic	127	266	132	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	136	264	128	-	-	-	-	-	-
		mesotrophic	135	265	130	-	-	-	-	-	-
		oligotrophic	135	266	131	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	169	257	88	-	-	-	-	-	-
		mesotrophic	177	260	83	-	-	-	-	-	-
		oligotrophic	200	265	65	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	165	260	95	-	-	-	-	-	-
		mesotrophic	167	261	94	-	-	-	-	-	-
		oligotrophic	172	266	94	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	159	266	107	-	-	-	-	-	-
		mesotrophic	164	267	103	-	-	-	-	-	-
		oligotrophic	164	268	104	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	181	255	74	-	-	-	-	-	-
		mesotrophic	0	0	0	56	333	233	45	67	687
		oligotrophic	0	0	0	57	335	279	0	94	909
	MEDIUM (1.7)	eutrophic	177	257	80	-	-	-	-	-	-
		mesotrophic	194	257	63	-	-	-	-	-	-
		oligotrophic	0	0	0	58	334	268	9	123	882
	LARGE (10.0)	eutrophic	174	265	91	-	-	-	-	-	-
		mesotrophic	190	261	71	-	-	-	-	-	-
		oligotrophic	235	260	25	-	-	-	-	-	-

Table 13b. **Cool-water** fish survival and growth parameters in lakes for projected $\mathbf{2xCO_2}$ **CCC** climate scenario at **Kansas City**, **MO.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	97	300	163	41	104	161
		mesotrophic	181	211	6	97	300	137	67	116	167
		oligotrophic	179	220	35	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	0	0	0	97	300	161	42	124	151
		mesotrophic	181	203	5	97	300	139	64	121	147
		oligotrophic	179	212	27	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	181	195	1	97	300	142	59	130	158
		mesotrophic	180	207	11	-	-	-	-	-	-
		oligotrophic	180	211	22	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	97	302	204	2	56	324
		mesotrophic	0	0	0	97	304	198	10	75	415
		oligotrophic	0	0	0	99	305	207	0	97	508
	MEDIUM (1.7)	eutrophic	0	0	0	99	302	203	1	99	426
		mesotrophic	0	0	0	99	302	201	3	106	451
		oligotrophic	0	0	0	100	303	194	10	115	476
	LARGE (10.0)	eutrophic	0	0	0	100	301	182	20	122	503
		mesotrophic	0	0	0	100	301	189	13	128	520
		oligotrophic	0	0	0	101	301	179	22	130	517
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	97	303	207	0	38	409
		mesotrophic	0	0	0	97	305	208	0	56	590
		oligotrophic	0	0	0	100	306	207	0	72	742
	MEDIUM (1.7)	eutrophic	0	0	0	100	305	206	0	73	609
		mesotrophic	0	0	0	100	305	206	0	82	673
		oligotrophic	0	0	0	102	306	205	0	107	856
	LARGE (10.0)	eutrophic	0	0	0	103	306	204	0	106	843
		mesotrophic	0	0	0	103	306	204	0	115	907
		oligotrophic	0	0	0	103	306	204	0	131	1011

Table 13c. **Warmwater** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Kansas City**, **MO.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	107	281	174	0	137	221
		mesotrophic	0	0	0	107	281	175	0	170	248
		oligotrophic	0	0	0	107	281	175	0	175	252
	MEDIUM (1.7)	eutrophic	0	0	0	107	281	171	0	167	207
		mesotrophic	0	0	0	107	281	171	0	170	209
		oligotrophic	0	0	0	107	281	171	0	171	209
	LARGE (10.0)	eutrophic	0	0	0	107	278	168	0	168	206
		mesotrophic	0	0	0	107	278	168	0	168	206
		oligotrophic	0	0	0	107	278	168	0	168	206
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	107	284	177	0	67	388
		mesotrophic	0	0	0	107	288	181	0	94	533
		oligotrophic	0	0	0	108	289	180	0	126	680
	MEDIUM (1.7)	eutrophic	0	0	0	108	284	176	0	111	494
		mesotrophic	0	0	0	108	284	175	0	127	556
		oligotrophic	0	0	0	112	285	174	0	148	628
	LARGE (10.0)	eutrophic	0	0	0	112	283	172	0	143	610
		mesotrophic	0	0	0	112	283	172	0	152	638
		oligotrophic	0	0	0	113	283	171	0	162	661
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	107	288	180	0	42	460
		mesotrophic	0	0	0	108	289	181	0	63	680
		oligotrophic	0	0	0	112	291	180	0	83	877
	MEDIUM (1.7)	eutrophic	0	0	0	112	288	177	0	76	636
		mesotrophic	0	0	0	112	288	177	0	88	733
		oligotrophic	0	0	0	113	290	178	0	114	932
	LARGE (10.0)	eutrophic	0	0	0	114	289	175	0	107	881
		mesotrophic	0	0	0	115	290	175	0	117	954
		oligotrophic	0	0	0	119	290	172	0	135	1080

Table 14a. **Differences** of **cold-water** fish survival and growth parameters between projected and past climate scenarios (**2xCO_2-PAST**) for lakes at **Kansas City, MO.**

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	32	-	-	-	-	-	-
		mesotrophic	33	-	-	-	-	-	-
		oligotrophic	39	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	35	-	-	-	-	-	-
		mesotrophic	32	-	-	-	-	-	-
		oligotrophic	34	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	34	-	-	-	-	-	-
		mesotrophic	33	-	-	-	-	-	-
		oligotrophic	33	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	42	-	-	-	-	-	-
		mesotrophic	42	-	-	-	-	-	-
		oligotrophic	54	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	37	-	-	-	-	-	-
		mesotrophic	39	-	-	-	-	-	-
		oligotrophic	42	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	37	-	-	-	-	-	-
		mesotrophic	34	-	-	-	-	-	-
		oligotrophic	33	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	39	-33	9	-1	43	9	98
		mesotrophic	0	-	-	-	-	-	-
		oligotrophic	0	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	69	-35	8	3	40	12	83
		mesotrophic	63	-35	8	1	42	12	82
		oligotrophic	0	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	60	-	-	-	-	-	-
		mesotrophic	71	-	-	-	-	-	-
		oligotrophic	25	-	-	-	-	-	-

Table 14b. **Differences** of **cool-water** fish survival and growth parameters between projected and past climate scenarios (**$2xCO_2$-PAST**) for lakes at **Kansas City, MO.**

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	-10	11	-17	41	-20	-35
		mesotrophic	6	-10	11	-43	67	-29	-42
		oligotrophic	35	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	0	-10	12	-13	42	-27	-34
		mesotrophic	5	-10	12	-35	64	-30	-37
		oligotrophic	27	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	1	-11	12	-28	59	-26	-32
		mesotrophic	11	-	-	-	-	-	-
		oligotrophic	22	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	-11	11	24	2	-7	-37
		mesotrophic	0	-16	9	16	10	-12	-74
		oligotrophic	0	-14	9	24	0	-18	-102
	MEDIUM (1.7)	eutrophic	0	-14	11	26	1	-9	-47
		mesotrophic	0	-14	11	24	3	-16	-76
		oligotrophic	0	-14	12	20	10	-23	-103
	LARGE (10.0)	eutrophic	0	-15	10	9	20	-21	-97
		mesotrophic	0	-20	10	17	13	-23	-106
		oligotrophic	0	-19	10	7	22	-29	-123
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-15	12	28	0	-2	-26
		mesotrophic	0	-16	9	25	0	-4	-53
		oligotrophic	0	-15	9	28	0	-5	-61
	MEDIUM (1.7)	eutrophic	0	-15	10	29	0	-3	-22
		mesotrophic	0	-20	10	30	0	-6	-55
		oligotrophic	0	-19	10	29	0	-5	-59
	LARGE (10.0)	eutrophic	0	-19	10	29	0	-8	-80
		mesotrophic	0	-20	10	30	0	-11	-103
		oligotrophic	0	-20	10	30	0	-16	-139

Table 14c. **Differences of warmwater** fish survival and growth parameters between projected and past climate scenarios (**$2xCO_2$-PAST**) for lakes at **Kansas City, MO.**

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	-20	4	24	0	23	35
		mesotrophic	0	-20	4	25	0	28	40
		oligotrophic	0	-20	4	25	0	28	39
	MEDIUM (1.7)	eutrophic	0	-20	8	31	0	32	39
		mesotrophic	0	-20	10	32	0	33	40
		oligotrophic	0	-20	10	32	0	32	39
	LARGE (10.0)	eutrophic	0	-23	12	35	0	35	43
		mesotrophic	0	-23	12	35	0	35	43
		oligotrophic	0	-23	12	35	0	36	44
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	-20	7	28	0	12	70
		mesotrophic	0	-23	10	34	0	17	95
		oligotrophic	0	-27	11	36	0	23	123
	MEDIUM (1.7)	eutrophic	0	-26	7	32	0	22	97
		mesotrophic	0	-27	7	32	0	23	101
		oligotrophic	0	-23	8	31	0	26	109
	LARGE (10.0)	eutrophic	0	-23	6	29	0	26	110
		mesotrophic	0	-23	7	30	0	27	115
		oligotrophic	0	-23	7	30	0	29	116
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-20	11	31	0	8	91
		mesotrophic	0	-22	11	35	0	14	147
		oligotrophic	0	-23	12	35	0	18	186
	MEDIUM (1.7)	eutrophic	0	-23	11	34	0	16	135
		mesotrophic	0	-23	11	34	0	18	148
		oligotrophic	0	-22	12	34	0	26	210
	LARGE (10.0)	eutrophic	0	-22	11	32	0	21	176
		mesotrophic	0	-22	12	33	0	23	187
		oligotrophic	0	-18	12	30	0	28	224

Table 15a. **Cold-water** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Austin, TX.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	140	270	130	-	-	-	-	-	-
		mesotrophic	130	286	153	-	-	-	-	-	-
		oligotrophic	114	287	163	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	138	270	132	-	-	-	-	-	-
		mesotrophic	129	284	150	-	-	-	-	-	-
		oligotrophic	115	286	159	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	129	277	145	-	-	-	-	-	-
		mesotrophic	115	284	152	-	-	-	-	-	-
		oligotrophic	115	284	153	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	159	267	108	-	-	-	-	-	-
		mesotrophic	162	270	108	-	-	-	-	-	-
		oligotrophic	173	278	105	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	151	270	119	-	-	-	-	-	-
		mesotrophic	156	270	114	-	-	-	-	-	-
		oligotrophic	158	280	122	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	148	276	128	-	-	-	-	-	-
		mesotrophic	150	277	127	-	-	-	-	-	-
		oligotrophic	150	278	128	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	168	263	95	-	-	-	-	-	-
		mesotrophic	225	265	40	-	-	-	-	-	-
		oligotrophic	0	0	0	1	366	365	0	154	1436
	MEDIUM (1.7)	eutrophic	168	266	98	-	-	-	-	-	-
		mesotrophic	182	266	84	-	-	-	-	-	-
		oligotrophic	0	0	0	1	366	291	66	162	1170
	LARGE (10.0)	eutrophic	166	277	111	-	-	-	-	-	-
		mesotrophic	178	274	96	-	-	-	-	-	-
		oligotrophic	214	275	61	-	-	-	-	-	-

Table 15b. **Cool-water** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Austin, TX.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	206	236	1	74	318	168	76	121	192
		mesotrophic	185	236	31	-	-	-	-	-	-
		oligotrophic	181	240	49	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	0	0	0	77	318	164	75	144	177
		mesotrophic	185	236	13	-	-	-	-	-	-
		oligotrophic	183	236	26	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	223	223	0	77	316	153	83	147	180
		mesotrophic	206	236	6	77	316	151	85	148	181
		oligotrophic	204	236	9	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	77	325	218	29	67	384
		mesotrophic	0	0	0	77	325	202	47	91	507
		oligotrophic	0	0	0	77	326	203	47	120	627
	MEDIUM (1.7)	eutrophic	0	0	0	77	322	217	29	115	501
		mesotrophic	0	0	0	78	322	207	38	127	541
		oligotrophic	0	0	0	78	322	191	54	140	580
	LARGE (10.0)	eutrophic	0	0	0	79	321	179	61	139	580
		mesotrophic	0	0	0	79	321	182	57	145	593
		oligotrophic	0	0	0	79	321	179	60	149	598
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	77	325	249	0	45	483
		mesotrophic	0	0	0	77	326	250	0	67	715
		oligotrophic	0	0	0	79	331	253	0	98	1000
	MEDIUM (1.7)	eutrophic	0	0	0	79	326	246	0	85	705
		mesotrophic	0	0	0	79	326	245	0	96	793
		oligotrophic	0	0	0	82	328	246	0	127	1022
	LARGE (10.0)	eutrophic	0	0	0	86	326	241	0	121	966
		mesotrophic	0	0	0	87	326	240	0	131	1037
		oligotrophic	0	0	0	87	326	240	0	151	1153

Table 15c. **Warmwater** fish survival and growth parameters in lakes under **past climate** conditions (1961-1979) at **Austin, TX.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	94	305	209	0	167	270
		mesotrophic	0	0	0	94	305	209	0	206	298
		oligotrophic	0	0	0	94	305	209	0	208	300
	MEDIUM (1.7)	eutrophic	0	0	0	98	305	206	0	202	250
		mesotrophic	0	0	0	98	305	206	0	206	252
		oligotrophic	0	0	0	98	305	206	0	206	252
	LARGE (10.0)	eutrophic	0	0	0	98	305	205	0	204	251
		mesotrophic	0	0	0	98	305	205	0	204	250
		oligotrophic	0	0	0	98	305	205	0	204	250
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	98	306	209	0	82	476
		mesotrophic	0	0	0	98	307	210	0	116	652
		oligotrophic	0	0	0	99	308	210	0	155	829
	MEDIUM (1.7)	eutrophic	0	0	0	99	306	208	0	136	601
		mesotrophic	0	0	0	100	306	207	0	157	683
		oligotrophic	0	0	0	100	306	207	0	182	768
	LARGE (10.0)	eutrophic	0	0	0	100	305	206	0	174	738
		mesotrophic	0	0	0	101	305	205	0	186	775
		oligotrophic	0	0	0	101	305	205	0	199	805
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	98	307	210	0	51	551
		mesotrophic	0	0	0	99	308	210	0	77	831
		oligotrophic	0	0	0	100	310	211	0	107	1123
	MEDIUM (1.7)	eutrophic	0	0	0	100	307	208	0	91	763
		mesotrophic	0	0	0	100	307	208	0	106	887
		oligotrophic	0	0	0	101	309	209	0	141	1151
	LARGE (10.0)	eutrophic	0	0	0	102	308	207	0	130	1060
		mesotrophic	0	0	0	103	308	206	0	143	1156
		oligotrophic	0	0	0	103	308	206	0	167	1318

Table 16a. **Cold-water** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Austin, TX.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	$\frac{A(z)*Jd}{As}$ (day)	$\frac{V(z)*Jd}{As}$ (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	110	289	173	-	-	-	-	-	-
		mesotrophic	107	297	188	-	-	-	-	-	-
		oligotrophic	99	298	199	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	108	289	181	-	-	-	-	-	-
		mesotrophic	102	297	192	-	-	-	-	-	-
		oligotrophic	98	297	198	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	100	296	191	-	-	-	-	-	-
		mesotrophic	98	297	195	-	-	-	-	-	-
		oligotrophic	98	297	196	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	140	288	148	-	-	-	-	-	-
		mesotrophic	145	292	147	-	-	-	-	-	-
		oligotrophic	145	298	153	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	138	291	153	-	-	-	-	-	-
		mesotrophic	138	292	154	-	-	-	-	-	-
		oligotrophic	136	298	162	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	117	293	172	-	-	-	-	-	-
		mesotrophic	130	296	166	-	-	-	-	-	-
		oligotrophic	127	297	170	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	147	284	137	-	-	-	-	-	-
		mesotrophic	184	290	106	-	-	-	-	-	-
		oligotrophic	0	0	0	1	366	295	71	143	1248
	MEDIUM (1.7)	eutrophic	147	289	142	-	-	-	-	-	-
		mesotrophic	157	290	133	-	-	-	-	-	-
		oligotrophic	215	292	77	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	144	300	156	-	-	-	-	-	-
		mesotrophic	154	299	145	-	-	-	-	-	-
		oligotrophic	183	301	118	-	-	-	-	-	-

Table 16b. **Cool-water** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Austin, TX.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	166	253	78	-	-	-	-	-	-
		mesotrophic	165	253	88	-	-	-	-	-	-
		oligotrophic	149	256	100	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	170	252	74	-	-	-	-	-	-
		mesotrophic	165	252	87	-	-	-	-	-	-
		oligotrophic	158	253	91	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	165	252	83	-	-	-	-	-	-
		mesotrophic	165	252	86	-	-	-	-	-	-
		oligotrophic	165	252	86	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	202	244	33	-	-	-	-	-	-
		mesotrophic	189	250	45	-	-	-	-	-	-
		oligotrophic	191	253	61	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	205	248	33	-	-	-	-	-	-
		mesotrophic	205	248	36	-	-	-	-	-	-
		oligotrophic	205	251	46	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	186	250	57	-	-	-	-	-	-
		mesotrophic	205	249	42	-	-	-	-	-	-
		oligotrophic	190	251	61	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	41	343	227	75	48	516
		mesotrophic	0	0	0	41	345	259	46	72	765
		oligotrophic	0	0	0	42	347	306	0	112	1140
	MEDIUM (1.7)	eutrophic	235	236	1	43	344	229	73	93	772
		mesotrophic	0	0	0	43	344	237	65	105	867
		oligotrophic	0	0	0	43	345	303	0	138	1100
	LARGE (10.0)	eutrophic	0	0	0	44	344	222	79	130	1042
		mesotrophic	0	0	0	44	344	233	68	142	1121
		oligotrophic	0	0	0	44	344	264	37	163	1239

Table 16c. **Warmwater** fish survival and growth parameters in lakes for projected **$2xCO_2$ CCC** climate scenario at **Austin, TX.**

LAKE CHARACTERISTICS			SURVIVAL			GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	0	0	59	318	234	6	153	246
		mesotrophic	0	0	0	59	318	215	27	186	270
		oligotrophic	0	0	0	59	318	194	48	190	274
	MEDIUM (1.7)	eutrophic	0	0	0	59	316	237	0	209	259
		mesotrophic	0	0	0	59	316	222	15	214	262
		oligotrophic	0	0	0	59	316	215	22	215	263
	LARGE (10.0)	eutrophic	0	0	0	59	316	230	5	222	272
		mesotrophic	0	0	0	59	316	225	10	223	273
		oligotrophic	0	0	0	59	316	223	12	223	273
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	0	0	59	322	248	0	80	463
		mesotrophic	0	0	0	59	325	250	0	113	631
		oligotrophic	0	0	0	60	325	249	0	149	788
	MEDIUM (1.7)	eutrophic	0	0	0	60	321	242	0	143	633
		mesotrophic	0	0	0	60	321	241	0	166	720
		oligotrophic	0	0	0	60	322	242	0	191	803
	LARGE (10.0)	eutrophic	0	0	0	60	319	238	0	185	796
		mesotrophic	0	0	0	60	319	236	0	204	852
		oligotrophic	0	0	0	60	319	235	0	218	886
DEEP (24.0)	SMALL (0.2)	eutrophic	0	0	0	59	325	249	0	51	554
		mesotrophic	0	0	0	60	325	250	0	78	834
		oligotrophic	0	0	0	60	328	249	0	116	1199
	MEDIUM (1.7)	eutrophic	0	0	0	60	325	244	0	100	838
		mesotrophic	0	0	0	60	325	244	0	117	972
		oligotrophic	0	0	0	60	326	244	0	155	1265
	LARGE (10.0)	eutrophic	0	0	0	60	325	240	0	148	1203
		mesotrophic	0	0	0	60	325	240	0	164	1324
		oligotrophic	0	0	0	60	325	240	0	192	1513

Table 17a. **Differences** of **cold-water** fish survival and growth parameters between projected and past climate scenarios (**$2xCO_2$-PAST**) for lakes at **Austin, TX**.

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	43	-	-	-	-	-	-
		mesotrophic	35	-	-	-	-	-	-
		oligotrophic	36	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	49	-	-	-	-	-	-
		mesotrophic	42	-	-	-	-	-	-
		oligotrophic	39	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	46	-	-	-	-	-	-
		mesotrophic	43	-	-	-	-	-	-
		oligotrophic	43	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	40	-	-	-	-	-	-
		mesotrophic	39	-	-	-	-	-	-
		oligotrophic	48	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	34	-	-	-	-	-	-
		mesotrophic	40	-	-	-	-	-	-
		oligotrophic	40	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	44	-	-	-	-	-	-
		mesotrophic	39	-	-	-	-	-	-
		oligotrophic	42	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	42	-	-	-	-	-	-
		mesotrophic	66	-	-	-	-	-	-
		oligotrophic	0	0	0	-70	71	-11	-188
	MEDIUM (1.7)	eutrophic	44	-	-	-	-	-	-
		mesotrophic	49	-	-	-	-	-	-
		oligotrophic	77	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	-80	-	-	-	-	-	-
		mesotrophic	-96	-	-	-	-	-	-
		oligotrophic	-61	-	-	-	-	-	-

Table 17b. **Differences** of **cool-water** fish survival and growth parameters between projected and past climate scenarios **($2xCO_2$-PAST)** for lakes at **Austin, TX**.

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	$\frac{A(z)*Jd}{As}$ (day)	$\frac{V(z)*Jd}{As}$ (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	77	-	-	-	-	-	-
		mesotrophic	57	-	-	-	-	-	-
		oligotrophic	51	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	74	-	-	-	-	-	-
		mesotrophic	74	-	-	-	-	-	-
		oligotrophic	65	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	83	-	-	-	-	-	-
		mesotrophic	80	-	-	-	-	-	-
		oligotrophic	77	-	-	-	-	-	-
MEDIUM (13.0)	SMALL (0.2)	eutrophic	33	-	-	-	-	-	-
		mesotrophic	45	-	-	-	-	-	-
		oligotrophic	61	-	-	-	-	-	-
	MEDIUM (1.7)	eutrophic	33	-	-	-	-	-	-
		mesotrophic	36	-	-	-	-	-	-
		oligotrophic	46	-	-	-	-	-	-
	LARGE (10.0)	eutrophic	57	-	-	-	-	-	-
		mesotrophic	42	-	-	-	-	-	-
		oligotrophic	61	-	-	-	-	-	-
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-36	18	-22	75	3	33
		mesotrophic	0	-36	19	9	46	5	50
		oligotrophic	0	-37	16	53	0	14	140
	MEDIUM (1.7)	eutrophic	1	-36	18	-17	73	8	67
		mesotrophic	0	-36	18	-8	65	9	74
		oligotrophic	0	-39	17	57	0	11	78
	LARGE (10.0)	eutrophic	0	-42	18	-19	79	9	76
		mesotrophic	0	-43	18	-7	68	11	84
		oligotrophic	0	-43	18	24	37	12	86

Table 17c. **Differences** of **warmwater** fish survival and growth parameters between projected and past climate scenarios (**$2xCO_2$-PAST**) for lakes at **Austin, TX.**

LAKE CHARACTERISTICS			SURVIVAL	GROWTH					
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS	NSL (day)	GSB (day)	GSE (day)	GSL (day)	GZER (day)	A(z)*Jd / As (day)	V(z)*Jd / As (m day)
SHALLOW (4.0)	SMALL (0.2)	eutrophic	0	-35	13	25	6	-14	-24
		mesotrophic	0	-35	13	6	27	-20	-28
		oligotrophic	0	-35	13	-15	48	-18	-26
	MEDIUM (1.7)	eutrophic	0	-39	11	31	0	7	9
		mesotrophic	0	-39	11	16	15	8	10
		oligotrophic	0	-39	11	9	22	9	11
	LARGE (10.0)	eutrophic	0	-39	11	25	5	18	21
		mesotrophic	0	-39	11	20	10	19	23
		oligotrophic	0	-39	11	18	12	19	23
MEDIUM (13.0)	SMALL (0.2)	eutrophic	0	-39	16	39	0	-2	-13
		mesotrophic	0	-39	18	40	0	-3	-21
		oligotrophic	0	-39	17	39	0	-6	-41
	MEDIUM (1.7)	eutrophic	0	-39	15	34	0	7	32
		mesotrophic	0	-40	15	34	0	9	37
		oligotrophic	0	-40	16	35	0	9	35
	LARGE (10.0)	eutrophic	0	-40	14	32	0	11	58
		mesotrophic	0	-41	14	31	0	18	77
		oligotrophic	0	-41	14	30	0	19	81
DEEP (24.0)	SMALL (0.2)	eutrophic	0	-39	18	39	0	0	3
		mesotrophic	0	-39	17	40	0	1	3
		oligotrophic	0	-40	18	38	0	9	76
	MEDIUM (1.7)	eutrophic	0	-40	18	36	0	9	75
		mesotrophic	0	-40	18	36	0	11	85
		oligotrophic	0	-41	17	35	0	14	114
	LARGE (10.0)	eutrophic	0	-42	17	33	0	18	143
		mesotrophic	0	-43	17	34	0	21	168
		oligotrophic	0	-43	17	34	0	25	195

Table 18. Symbols used in Figs. 16 to 48 to classify fish habitat and its changes.

Case	Symbols Used	Designations	Description
Fish Habitat Status	●	"suitable habitat"	Fish habitat exists year round.
	◊	"summerkill"	*No fish habitat* over the entire depth for more than 7 days **during the summer period** (summerkill) under *either present or projected 2xCO_2* climate scenarios.
	◆	"winterkill"	*No fish habitat* over the entire depth for more than 7 days **during the ice-cover period (winterkill)** under *either present or projected 2xCO_2* climate scenarios.
Fish Habitat Changes	▲	"from habitat to summerkill"	*Having fish habitat* under the **present** climate conditions (1961-1979), *but no fish habitat* over the entire depth for more than 7 days *during the summer period* under the **projected** climate scenario.
	O	"from winterkill to summerkill"	*No fish habitat* over the entire depth for more than 7 days **shifted from** the *ice-cover period* under the **present** climate conditions to the *summer period* under the **projected** climate scenario.
	■	"from winterkill to habitat"	*No fish habitat* over the entire depth for more than 7 days *during the ice-cover period* under the **present** climate conditions (1961-1979), but with **fish habitat** *under the **projected** climate scenario.*

Table 19a. Comparison of observed fish guilds and simulated habitat with consideration of possible winterkill in 2231 lakes near **Duluth, MN.**

LAKE CHARACTERISTICS				OBSERVED FISH GUILD			SIMULATED FISH GUILD			CONCLUSION FISH GUILD		
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS [1]	NUMBER OF LAKES	COLD	COOL	WARM	COLD	COOL	WARM	COLD	COOL	WARM
SHALLOW (4.0)	SMALL (0.2)	E	185	ND	Y	Y	N	N	N	ND	D	D
		M	189	Y	Y	Y	N	N	N	D	D	D
		O	3	Y	Y	Y	Y	Y	Y	A	A	A
	MEDIUM (1.7)	E	150	Y	Y	Y	N	N	N	D	D	D
		M	99	Y	Y	Y	N	N	N	D	D	D
		O	2	ND	Y	Y	Y	Y	Y	ND	A	A
	LARGE (10.0)	E	7	Y	Y	Y	N	N	N	D	D	D
		M	3	Y	Y	Y	N	N	N	D	D	D
		O	0	0	0	0	Y	Y	Y	0	0	0
MEDIUM (13.0)	SMALL (0.2)	E	85	ND	Y	Y	Y	Y	Y	ND	A	A
		M	350	Y	Y	Y	Y	Y	Y	A	A	A
		O	76	Y	Y	Y	Y	Y	Y	A	A	A
	MEDIUM (1.7)	E	102	Y	Y	Y	Y	Y	Y	A	A	A
		M	531	Y	Y	Y	Y	Y	Y	A	A	A
		O	78	Y	Y	Y	Y	Y	Y	A	A	A
	LARGE (10.0)	E	14	Y	Y	Y	Y	Y	Y	A	A	A
		M	46	Y	Y	Y	Y	Y	Y	A	A	A
		O	2	Y	Y	Y	Y	Y	Y	A	A	A
DEEP (24.0)	SMALL (0.2)	E	6	ND	Y	Y	Y	Y	Y	ND	A	A
		M	26	Y	Y	Y	Y	Y	Y	A	A	A
		O	26	Y	Y	Y	Y	Y	Y	A	A	A
	MEDIUM (1.7)	E	3	Y	Y	Y	Y	Y	Y	A	A	A
		M	103	Y	Y	Y	Y	Y	Y	A	A	A
		O	69	Y	Y	Y	Y	Y	Y	A	A	A
	LARGE (10.0)	E	5	Y	Y	Y	Y	Y	Y	A	A	A
		M	54	Y	Y	Y	Y	Y	Y	A	A	A
		O	17	Y	Y	Y	Y	Y	Y	A	A	A

Note: **Y** : Fish guilds were observed or fish habitats were simulated by model.
N : No fish habitats were simulated (non-survival conditions).
A : Agreement between simulated habitat and observed fish (shown as shaded cells).
D : Disagreement between simulated habitat and observed fish.
ND: No data are available.
0 : No lake exists in the database.
[1] : E = Eutrophic, M = Mesotrophic, and O = Oligotrophic.

Table 19b. Comparison of observed fish guilds and simulated habitat with consideration of possible winterkill in 771 lakes near **Minneapolis, MN.**

LAKE CHARACTERISTICS				OBSERVED FISH GUILD			SIMULATED FISH GUILD			CONCLUSION FISH GUILD		
MAXIMUM DEPTH (m)	SURFACE AREA (km^2)	TROPHIC STATUS [1]	NUMBER OF LAKES	COLD	COOL	WARM	COLD	COOL	WARM	COLD	COOL	WARM
SHALLOW (4.0)	SMALL (0.2)	E	45	ND	Y	Y	N	N	N	ND	D	D
		M	12	ND	Y	Y	N	Y	Y	ND	A	A
		O	1	ND	ND	Y	N	Y	Y	ND	ND	A
	MEDIUM (1.7)	E	168	ND	Y	Y	N	N	N	ND	D	D
		M	25	ND	Y	Y	N	N	N	ND	D	D
		O	2	ND	ND	ND	N	Y	Y	ND	ND	ND
	LARGE (10.0)	E	19	Y	Y	Y	N	N	N	D	D	D
		M	2	ND	Y	Y	N	N	N	ND	D	D
		O	0	0	0	0	N	Y	Y	0	0	0
MEDIUM (13.0)	SMALL (0.2)	E	82	ND	Y	Y	Y	Y	Y	ND	A	A
		M	71	Y	Y	Y	Y	Y	Y	A	A	A
		O	6	ND	Y	Y	Y	Y	Y	ND	A	A
	MEDIUM (1.7)	E	142	Y	Y	Y	Y	Y	Y	A	A	A
		M	102	Y	Y	Y	Y	Y	Y	A	A	A
		O	7	ND	Y	Y	Y	Y	Y	ND	A	A
	LARGE (10.0)	E	17	Y	Y	Y	Y	Y	Y	A	A	A
		M	5	Y	Y	Y	Y	Y	Y	A	A	A
		O	0	0	0	0	Y	Y	Y	0	0	0
DEEP (24.0)	SMALL (0.2)	E	1	ND	Y	ND	Y	Y	Y	ND	A	ND
		M	7	Y	Y	Y	Y	Y	Y	A	A	A
		O	0	0	0	0	Y	Y	Y	0	0	0
	MEDIUM (1.7)	E	10	Y	Y	Y	Y	Y	Y	A	A	A
		M	33	Y	Y	Y	Y	Y	Y	A	A	A
		O	3	ND	Y	Y	Y	Y	Y	ND	A	A
	LARGE (10.0)	E	5	Y	Y	Y	Y	Y	Y	A	A	A
		M	6	Y	Y	Y	Y	Y	Y	A	A	A
		O	0	0	0	0	Y	Y	Y	0	0	0

Note:
Y : Fish guilds were observed or fish habitats were simulated by model.
N : No fish habitats were simulated (non-survival conditions).
A : Agreement between simulated habitat and observed fish (shown as shaded cells).
D : Disagreement between simulated habitat and observed fish.
ND: No data are available.
0 : No lake exists in the database.
[1] : E = Eutrophic, M = Mesotrophic, and O = Oliogotrophic.

Table 20a. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under past climate conditions (1961-1979) at **Duluth**, **MN,** *when winter DO survival limit was set at 0.0 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	0	0	0	55	67	13
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	44	68	25
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	55	67	13
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	44	68	25
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	55	67	13
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	44	68	25
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0

Table 20b. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under past climate conditions (1961-1979) at **Duluth**, **MN,** *when winter DO survival limit was set at 0.5 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	0	0	0	44	81	38
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	32	83	52
		mesotrophic	0	0	0	63	89	27
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	30	83	54
		mesotrophic	0	0	0	64	90	27
		oligotrophic	0	0	0	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	44	81	38
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	32	83	52
		mesotrophic	0	0	0	63	89	27
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	30	83	54
		mesotrophic	0	0	0	64	90	27
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	44	81	38
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	32	83	52
		mesotrophic	0	0	0	64	90	27
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	30	83	54
		mesotrophic	0	0	0	64	90	27
		oligotrophic	0	0	0	0	0	0

Table 20c. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under past climate conditions (1961-1979) at **Duluth, MN,** *when winter DO survival limit was set at 1.0 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	0	0	0	39	86	48
		mesotrophic	0	0	0	80	86	7
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	27	86	60
		mesotrophic	0	0	0	58	94	36
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	26	87	62
		mesotrophic	0	0	0	58	94	36
		oligotrophic	0	0	0	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	39	86	48
		mesotrophic	0	0	0	80	86	7
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	27	86	60
		mesotrophic	0	0	0	58	94	36
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	26	87	62
		mesotrophic	0	0	0	58	94	36
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	39	86	48
		mesotrophic	0	0	0	80	86	7
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	27	86	60
		mesotrophic	0	0	0	58	94	36
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	26	87	62
		mesotrophic	0	0	0	58	94	36
		oligotrophic	0	0	0	0	0	0

Table 20d. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under past climate conditions (1961-1979) at **Minneapolis, MN,** *when winter DO survival limit was set at 0.0 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	199	207	4	0	0	0
		mesotrophic	186	220	34	0	0	0
		oligotrophic	178	233	54	0	0	0
	MEDIUM (1.7)	eutrophic	199	208	5	0	0	0
		mesotrophic	182	219	37	0	0	0
		oligotrophic	178	230	46	0	0	0
	LARGE (10.0)	eutrophic	180	219	31	0	0	0
		mesotrophic	179	221	40	0	0	0
		oligotrophic	179	221	42	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0

Table 20e. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under past climate conditions (1961-1979) at **Minneapolis, MN,** *when winter DO survival limit was set at 0.5 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	199	207	4	0	0	0
		mesotrophic	186	220	34	0	0	0
		oligotrophic	178	233	54	0	0	0
	MEDIUM (1.7)	eutrophic	199	208	5	55	66	11
		mesotrophic	182	219	37	0	0	0
		oligotrophic	178	230	46	0	0	0
	LARGE (10.0)	eutrophic	180	219	31	53	66	13
		mesotrophic	179	221	40	0	0	0
		oligotrophic	179	221	42	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	55	66	11
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	53	66	13
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	55	66	11
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	53	66	13
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0

Table 20f. Fish **survival** parameters for three fish guilds during the open water season (summer) and the ice-cover period (winter) in **shallow lakes** under past climate conditions (1961-1979) at **Minneapolis, MN,** *when winter DO survival limit was set at 1.0 mg/l.*

FISH GUILD	LAKE CHARACTERISTICS		SUMMER			WINTER		
	SURFACE AREA (km^2)	TROPHIC STATUS	NSB (day)	NSE (day)	NSL (day)	NSB (day)	NSE (day)	NSL (day)
COLD	SMALL (0.2)	eutrophic	199	207	4	0	0	0
		mesotrophic	186	220	34	0	0	0
		oligotrophic	178	233	54	0	0	0
	MEDIUM (1.7)	eutrophic	199	208	5	46	74	28
		mesotrophic	182	219	37	0	0	0
		oligotrophic	178	230	46	0	0	0
	LARGE (10.0)	eutrophic	180	219	31	44	74	30
		mesotrophic	179	221	40	0	0	0
		oligotrophic	179	221	42	0	0	0
COOL	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	46	74	28
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	44	74	30
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
WARM	SMALL (0.2)	eutrophic	0	0	0	0	0	0
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	MEDIUM (1.7)	eutrophic	0	0	0	46	74	28
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0
	LARGE (10.0)	eutrophic	0	0	0	44	74	30
		mesotrophic	0	0	0	0	0	0
		oligotrophic	0	0	0	0	0	0

Table 20g. Observed fish guilds and sensitivity of simulated fish habitats to DO survival limits for winterkill in shallow lakes in northern and southern Minnesota.

LAKE CHARACTERISTICS				OBSERVED FISH GUILDS			DO LIMIT = 0.0 mg/L FISH GUILDS			DO LIMIT = 0.5 mg/L FISH GUILDS			DO LIMIT = 1.0 mg/L FISH GUILDS		
LOCATION	SURFACE AREA (km^2)	TROPHIC STATUS [1]	NUMBER OF LAKES	COLD	COOL	WARM	COLD	COOL	WARM	COLD	COOL	WARM	COLD	COOL	WARM
NORTHERN MINNESOTA	SAMLL (0.2)	E	185	ND	Y	Y	ND	D	D	ND	D	D	ND	D	D
		M	189	Y	Y	Y	A	A	A	A	A	A	A	A	A
		O	3	Y	Y	Y	A	A	A	A	A	A	A	A	A
	MEDIUM (1.7)	E	150	Y	Y	Y	D	D	D	D	D	D	D	D	D
		M	99	Y	Y	Y	A	A	A	D	D	D	D	D	D
		O	2	ND	Y	Y	ND	A	A	ND	A	A	ND	A	A
	LARGE (10.0)	E	7	Y	Y	Y	A	A	A	D	D	D	D	D	D
		M	3	Y	Y	Y	A	A	A	D	D	D	D	D	D
		O	0	0	0	0	0	0	0	0	0	0	0	0	0
SOUTHERN MINNESOTA	SMALL (0.2)	E	45	ND	Y	Y	ND	A	A	ND	A	A	ND	A	A
		M	12	ND	Y	Y	ND	A	A	ND	A	A	ND	A	A
		O	1	ND	N	Y	ND	ND	A	ND	ND	A	ND	ND	A
	MEDIUM (1.7)	E	168	ND	Y	Y	ND	A	A	ND	D	D	ND	D	D
		M	25	ND	Y	Y	ND	A	A	ND	A	A	ND	A	A
		O	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	LARGE (10.0)	E	19	Y	Y	Y	A	A	A	D	D	D	D	D	D
		M	2	ND	Y	Y	ND	A	A	ND	A	A	ND	A	A
		O	0	0	0	0	0	0	0	0	0	0	0	0	0

Note:

Y : Fish guilds were observed.
A : Agreement between simulated habitat and observed fish (shown as shaded cells).
D : Disagreement between simulated habitat and observed fish.
ND: No data are available.
0 : No lake exists in the database.
[1] : E = Eutrophic, M = Mesotrophic, and O = Oliogotrophic.

Table 21a. Maximum and minimum, mean and standard deviation (STD) of three habitat parameters for **cold-water fish** simulated for 27 lake types in the contiguous U.S. under **past (1962-1979) climate** conditions.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	264	105	137	38	223	72	100	30	221	75	100	32
			M	230	89	124	37	220	76	112	36	219	76	111	36
			O	220	78	123	45	219	73	120	42	219	72	120	43
	Medium (1.7)	9.0	E	239	96	128	36	225	76	105	33	225	74	104	32
			M	230	85	127	40	225	74	118	41	225	74	118	40
			O	230	79	122	42	225	74	119	41	225	74	119	42
	Large (10)	14.1	E	231	92	131	41	227	85	122	40	227	84	121	42
			M	231	84	127	42	230	74	123	44	230	73	123	43
			O	231	81	121	43	231	78	119	44	231	78	119	45
Medium (13.0)	Small (0.2)	1.6	E	348	130	161	34	205	44	67	22	179	10	77	18
			M	348	140	172	31	212	58	79	21	184	12	87	19
			O	339	154	184	24	227	75	94	23	187	16	96	19
	Medium (1.7)	2.8	E	338	117	150	33	232	70	96	26	229	74	99	24
			M	330	123	151	32	231	73	98	25	228	75	99	24
			O	269	118	148	29	227	76	99	26	226	74	98	25
	Large (10)	4.3	E	278	98	131	33	229	74	101	29	228	73	101	27
			M	256	97	132	32	229	74	101	29	228	72	100	28
			O	248	94	127	31	228	72	100	30	227	71	99	28
Deep (24.0)	Small (0.2)	0.9	E	362	148	186	27	165	33	49	16	112	40	58	14
			M	361	150	215	34	181	46	67	15	114	1	74	16
			O	366	152	243	62	239	57	97	37	116	2	78	26
	Medium (1.7)	1.5	E	352	138	178	31	236	63	88	23	124	1	87	21
			M	351	151	195	24	244	74	99	22	132	6	97	21
			O	350	152	226	43	252	84	122	27	135	0	99	35
	Large (10)	2.3	E	347	127	164	32	247	84	107	24	135	6	99	20
			M	346	139	181	26	248	93	114	26	135	4	101	26
			O	329	149	201	26	246	96	120	23	135	1	102	27

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 21b. Maximum and minimum, mean and standard deviation (STD) of three habitat parameters for **cold-water fish** simulated for 27 lake types in the contiguous U.S. under **projected $2xCO_2$ climate scenario**.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	239	101	148	49	217	72	118	51	217	72	117	53
			M	221	106	162	48	216	96	154	52	216	96	154	51
			O	218	145	174	42	216	144	173	36	216	144	173	36
	Medium (1.7)	9.0	E	226	93	153	52	217	74	134	54	216	73	133	54
			M	217	101	160	50	216	93	155	51	216	92	155	51
			O	216	94	156	50	216	92	155	51	216	91	155	50
	Large (10)	14.1	E	222	103	174	48	219	94	169	51	219	93	168	54
			M	220	97	160	51	220	93	158	52	220	92	157	55
			O	221	94	159	52	221	92	157	55	221	92	157	55
Medium (13.0)	Small (0.2)	1.6	E	278	124	171	49	193	42	87	38	207	51	98	38
			M	271	128	173	43	207	55	94	38	193	3	95	36
			O	271	131	182	28	221	71	102	36	199	9	99	33
	Medium (1.7)	2.8	E	265	102	158	46	227	66	114	42	228	69	116	42
			M	264	102	157	46	228	69	114	44	228	71	115	42
			O	258	99	160	40	228	72	119	45	227	71	118	44
	Large (10)	4.3	E	250	87	147	47	235	70	122	48	233	69	122	46
			M	250	87	148	47	236	70	122	48	235	68	121	47
			O	244	97	149	46	234	68	126	50	234	66	125	50
Deep (24.0)	Small (0.2)	0.9	E	327	147	188	41	168	31	63	29	112	39	68	19
			M	352	159	223	34	194	46	78	22	115	1	84	19
			O	366	184	273	48	250	57	116	32	116	0	59	41
	Medium (1.7)	1.5	E	335	130	177	45	221	60	100	32	135	17	92	23
			M	366	138	190	40	235	72	107	29	135	3	100	23
			O	366	179	245	34	257	83	127	26	136	0	102	38
	Large (10)	2.3	E	281	98	164	40	238	78	116	37	131	1	88	35
			M	305	98	173	40	247	81	117	33	135	9	98	27
			O	335	98	202	37	251	80	120	25	134	2	100	28

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 21c. Maximum and minimum, mean and standard deviation (STD) of **differences** of three habitat parameters for **cold-water fish** between *projected* $2xCO_2$ *and past* climate scenarios for 27 lake types in the contiguous U.S.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	-8	-29	-19	11	25	-15	-3	19	31	-18	-3	23
			M	30	-24	-6	24	34	-18	-1	24	35	-18	0	24
			O	37	-19	3	29	36	-18	4	28	36	-18	4	28
	Medium (1.7)	9.0	E	26	-41	-15	21	32	-36	-6	21	33	-37	-5	22
			M	11	-23	-11	15	18	-19	-8	17	19	-20	-8	18
			O	17	-22	-9	17	19	-20	-7	18	19	-22	-8	18
	Large (10)	14.1	E	35	-26	-5	24	39	-17	0	23	39	-17	0	23
			M	2	-19	-9	9	3	-19	-10	9	3	-20	-10	10
			O	3	-19	-9	10	3	-20	-10	10	3	-21	-11	10
Medium (13.0)	Small (0.2)	1.6	E	59	-77	-19	28	58	-35	8	18	172	-7	14	34
			M	58	-85	-17	25	59	-38	4	17	169	-163	1	45
			O	41	-116	-7	25	51	-47	0	14	165	-169	-2	40
	Medium (1.7)	2.8	E	43	-113	-25	28	31	-37	-1	12	27	-35	-3	11
			M	32	-104	-25	27	29	-36	-2	12	27	-35	-4	12
			O	8	-63	-21	16	29	-36	-3	13	31	-37	-3	14
	Large (10)	4.3	E	6	-48	-20	17	24	-32	-6	12	25	-32	-6	13
			M	5	-45	-18	14	26	-32	-6	12	27	-32	-5	13
			O	20	-40	-10	13	31	-32	-4	14	30	-32	-4	14
Deep (24.0)	Small (0.2)	0.9	E	71	-65	-4	27	77	-22	11	17	42	-53	6	17
			M	96	-45	17	23	86	-22	14	15	84	-105	10	23
			O	108	-87	38	27	106	-50	25	20	76	-101	-20	49
	Medium (1.7)	1.5	E	79	-75	-16	32	48	-48	7	14	41	-51	5	13
			M	111	-116	-7	32	52	-97	6	16	45	-112	1	21
			O	111	-140	29	24	73	-103	10	15	46	-129	-6	39
	Large (10)	2.3	E	67	-116	-24	30	22	-47	-1	11	18	-131	-11	31
			M	79	-104	-16	30	22	-46	-2	10	20	-121	-5	16
			O	83	-79	4	29	26	-44	0	9	23	-128	-4	21

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 22a. Maximum and minimum, mean and standard deviation (STD) of three habitat parameters for **cool-water fish** simulated for 27 lake types in the contiguous U.S. under **past (1962-1979) climate** conditions.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	298	76	160	36	253	60	121	31	277	67	134	28
			M	297	77	151	31	297	73	141	31	297	74	143	28
			O	297	77	142	30	297	75	141	29	297	76	141	30
	Medium (1.7)	9.0	E	295	73	160	39	283	68	144	32	285	69	146	30
			M	287	72	151	33	285	70	145	32	286	70	145	31
			O	286	71	143	31	285	70	142	31	285	71	142	31
	Large (10)	14.1	E	281	66	153	36	276	65	147	34	277	66	147	35
			M	276	66	148	34	276	66	146	33	276	66	146	32
			O	276	66	144	32	275	66	143	34	275	66	143	34
Medium (13.0)	Small (0.2)	1.6	E	336	77	168	46	173	31	62	20	200	38	76	24
			M	317	77	167	44	207	42	86	22	212	17	100	25
			O	302	77	165	44	259	55	112	28	191	0	121	29
	Medium (1.7)	2.8	E	335	74	164	48	247	50	101	31	238	7	110	31
			M	325	74	163	48	257	56	115	32	244	9	122	31
			O	310	75	161	42	277	64	131	31	248	17	135	29
	Large (10)	4.3	E	315	70	158	44	273	59	127	32	236	9	130	32
			M	325	69	158	45	281	60	135	33	241	13	136	33
			O	308	69	156	40	282	62	142	32	244	11	140	33
Deep (24.0)	Small (0.2)	0.9	E	343	77	172	54	132	19	40	13	113	24	49	15
			M	340	77	173	54	159	27	58	17	106	0	66	19
			O	366	80	174	56	220	35	78	28	114	0	72	31
	Medium (1.7)	1.5	E	366	72	170	53	219	30	72	25	131	0	73	24
			M	366	73	170	53	233	37	83	28	135	0	84	26
			O	366	75	170	55	260	44	104	35	136	1	82	40
	Large (10)	2.3	E	366	68	167	54	260	41	101	33	134	1	87	34
			M	366	66	167	55	273	45	111	36	135	0	81	41
			O	366	63	167	54	287	48	127	39	135	1	71	43

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 22b. Maximum and minimum, mean and standard deviation (STD) of three habitat parameters for **cool-water fish** simulated for 27 lake types in the contiguous U.S. under projected **$2xCO_2$ climate scenario**.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	359	111	169	35	304	78	118	32	324	89	130	34
			M	337	111	159	31	335	96	139	36	335	98	141	34
			O	337	108	148	35	335	106	145	36	335	106	145	35
	Medium (1.7)	9.0	E	363	110	168	35	331	99	142	35	332	100	144	34
			M	334	110	158	35	333	104	146	33	333	103	146	32
			O	334	108	150	33	334	106	147	35	334	106	147	35
	Large (10)	14.1	E	349	96	159	35	341	82	148	35	341	84	148	36
			M	347	109	155	34	343	108	150	33	343	109	149	37
			O	344	109	152	34	344	108	151	33	344	109	150	38
Medium (13.0)	Small (0.2)	1.6	E	366	116	182	35	184	43	64	21	192	7	77	24
			M	366	115	181	37	243	63	88	24	209	31	100	23
			O	366	115	182	35	306	85	114	29	204	24	122	23
	Medium (1.7)	2.8	E	366	111	179	40	275	70	105	30	244	12	112	27
			M	366	111	178	39	303	84	119	33	233	38	124	24
			O	366	111	177	36	330	97	135	32	241	58	136	24
	Large (10)	4.3	E	366	108	173	35	317	83	130	32	233	45	132	27
			M	366	108	173	38	338	97	139	37	235	69	140	25
			O	366	108	171	35	350	105	147	34	236	71	144	25
Deep (24.0)	Small (0.2)	0.9	E	366	114	197	41	126	29	43	14	111	1	51	14
			M	366	116	201	46	174	43	63	16	113	5	73	13
			O	366	117	211	57	254	57	88	30	115	0	79	31
	Medium (1.7)	1.5	E	366	114	189	41	219	46	79	26	135	7	80	22
			M	366	113	195	40	242	62	91	28	133	0	91	25
			O	366	113	206	51	294	77	119	31	136	0	92	45
	Large (10)	2.3	E	366	110	188	38	280	67	109	30	135	1	94	35
			M	366	109	192	40	303	83	123	34	136	0	89	46
			O	366	109	199	45	341	93	143	34	136	0	56	52

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 22c. Maximum and minimum, mean and standard deviation (STD) of **differences** of three habitat parameters for **cool-water fish** between *projected 2xCO_2 and past* climate scenarios for 27 lake types in the contiguous U.S.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	110	-52	23	25	94	-48	0	23	105	-56	0	26
			M	109	-52	17	27	109	-61	2	29	108	-63	2	30
			O	109	-47	11	26	108	-50	9	27	108	-50	8	27
	Medium (1.7)	9.0	E	116	-57	23	28	113	-58	4	30	113	-60	4	31
			M	114	-45	19	26	113	-60	8	29	114	-61	7	30
			O	114	-54	15	26	114	-55	12	27	114	-56	12	27
	Large (10)	14.1	E	114	-49	21	28	114	-59	11	31	115	-59	11	32
			M	114	-54	18	28	114	-59	13	30	114	-59	13	30
			O	114	-50	17	27	115	-51	16	28	115	-51	16	28
Medium (13.0)	Small (0.2)	1.6	E	121	-62	27	26	66	-21	4	13	54	-136	4	18
			M	124	-63	27	26	90	-30	5	18	65	-165	2	25
			O	126	-43	31	21	108	-44	5	24	61	-141	2	28
	Medium (1.7)	2.8	E	127	-72	26	29	88	-32	7	19	64	-190	4	28
			M	124	-69	27	28	104	-42	8	24	72	-179	4	30
			O	127	-65	29	26	117	-51	8	28	78	-184	4	34
	Large (10)	4.3	E	123	-72	27	29	110	-52	8	26	73	-161	6	31
			M	123	-71	27	30	117	-59	10	29	75	-148	7	33
			O	125	-62	27	28	121	-70	11	32	76	-146	7	35
Deep (24.0)	Small (0.2)	0.9	E	129	-75	27	25	50	-25	3	9	85	-98	2	17
			M	134	-60	30	20	73	-15	6	12	88	-90	6	17
			O	135	-82	37	18	111	-43	10	16	108	-112	6	29
	Medium (1.7)	1.5	E	134	-103	27	28	82	-43	8	16	123	-124	8	23
			M	132	-99	28	26	94	-41	9	19	102	-124	8	26
			O	132	-83	35	19	117	-53	14	24	129	-121	10	46
	Large (10)	2.3	E	134	-90	28	29	98	-55	10	22	122	-125	6	40
			M	137	-100	27	30	112	-66	12	26	122	-117	6	51
			O	134	-88	32	23	126	-66	16	31	131	-129	-14	75

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 23a. Maximum and minimum, mean and standard deviation (STD) of three habitat parameters for **warmwater fish** simulated for 27 lake types in the contiguous U.S. under **past (1961-1979) climate** conditions.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	354	10	139	53	303	5	108	45	327	6	121	49
			M	354	7	136	53	347	5	131	52	350	6	133	53
			O	354	7	134	52	352	6	133	52	352	6	133	53
	Medium (1.7)	9.0	E	348	3	136	54	342	2	129	52	344	2	132	53
			M	348	2	133	53	346	2	131	54	347	2	132	53
			O	348	2	129	54	348	2	128	55	348	2	129	53
	Large (10)	14.1	E	343	0	131	57	341	0	129	56	342	0	130	56
			M	342	0	128	56	339	0	128	54	339	0	128	55
			O	340	0	125	54	340	0	125	54	339	0	125	54
Medium (13.0)	Small (0.2)	1.6	E	363	7	136	55	169	1	51	23	206	2	63	30
			M	364	5	136	55	229	2	73	32	194	2	85	38
			O	364	3	136	54	294	1	97	43	207	2	106	45
	Medium (1.7)	2.8	E	359	0	132	54	262	0	80	40	238	0	88	41
			M	358	0	131	55	290	0	95	45	251	0	103	46
			O	358	0	131	54	323	0	112	50	239	0	115	50
	Large (10)	4.3	E	349	0	128	54	306	0	102	47	227	0	105	47
			M	348	0	127	54	321	0	110	51	234	0	112	50
			O	347	0	126	56	333	0	119	54	243	0	118	52
Deep (24.0)	Small (0.2)	0.9	E	364	8	137	54	114	1	31	16	115	1	39	18
			M	365	5	137	54	158	1	46	23	111	1	54	26
			O	365	2	136	55	227	1	63	33	116	0	55	28
	Medium (1.7)	1.5	E	364	0	133	54	205	0	53	30	135	0	58	28
			M	364	0	132	55	226	0	63	33	135	0	67	31
			O	364	0	132	54	276	0	81	43	136	0	63	34
	Large (10)	2.3	E	361	0	128	57	261	0	73	41	133	0	65	34
			M	359	0	127	57	279	0	81	45	136	0	63	36
			O	359	0	127	56	309	0	94	51	135	0	64	34

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 23b. Maximum and minimum, mean and standard deviation (STD) of three habitat parameters for **warmwater fish** simulated for 27 lake types in the contiguous U.S. under **projected 2xCO_2 climate scenario**.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	365	88	164	47	317	60	120	38	341	70	135	41
			M	365	88	161	43	359	79	149	42	359	81	152	42
			O	359	88	156	38	359	83	154	39	359	83	154	40
	Medium (1.7)	9.0	E	365	80	163	47	362	71	147	44	363	73	151	44
			M	365	77	159	45	364	74	154	42	364	75	154	43
			O	364	76	155	44	364	74	154	44	364	74	155	41
	Large (10)	14.1	E	364	73	158	45	364	65	151	45	364	68	153	43
			M	364	72	157	44	364	71	155	43	364	72	155	43
			O	364	72	155	45	364	72	155	43	364	72	155	43
Medium (13.0)	Small (0.2)	1.6	E	365	87	173	53	186	29	62	22	210	9	76	24
			M	365	81	173	51	250	42	88	30	197	7	102	28
			O	365	80	172	50	320	56	117	38	207	7	125	31
	Medium (1.7)	2.8	E	365	78	170	52	285	44	99	36	245	0	107	34
			M	365	78	170	51	315	53	118	39	246	10	124	37
			O	365	78	169	50	349	64	138	42	249	4	139	37
	Large (10)	4.3	E	365	76	167	49	337	58	126	41	249	9	129	38
			M	365	76	166	50	354	62	139	43	247	1	138	38
			O	365	75	165	49	365	66	150	45	246	10	144	41
Deep (24.0)	Small (0.2)	0.9	E	365	85	174	54	130	18	40	13	104	8	48	16
			M	365	82	175	51	181	27	59	21	111	0	68	18
			O	365	83	176	51	260	36	82	32	116	0	74	29
	Medium (1.7)	1.5	E	365	78	172	51	230	26	69	28	134	0	70	25
			M	365	78	172	51	258	35	82	32	134	1	81	26
			O	365	79	172	52	310	46	108	38	136	1	85	37
	Large (10)	2.3	E	365	76	170	52	291	31	97	38	135	3	83	32
			M	365	75	169	52	314	38	109	42	136	1	84	37
			O	365	75	168	54	342	49	128	47	135	0	74	42

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 23c. Maximum and minimum, mean and standard deviation (STD) of **differences** of three habitat parameters for **warmwater fish** between *projected 2xCO₂ and past* climate scenarios for 27 lake types in the contiguous U.S.

Lake Characteristics				Good Growth Period				Good Growth Habitat Area				Good Growth Habitat Volume			
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)	Maximum (days)	Minimum (days)	Mean (days)	STD (days)
Shallow (4.0)	Small (0.2)	5.3	E	134	-74	28	28	110	-61	14	28	123	-70	16	32
			M	132	-74	26	29	135	-80	19	34	133	-80	20	35
			O	132	-80	21	34	131	-81	20	35	131	-81	21	35
	Medium (1.7)	9.0	E	135	-62	32	25	136	-69	22	32	136	-73	23	33
			M	135	-73	29	28	135	-76	25	32	136	-77	25	32
			O	135	-77	26	31	135	-78	26	31	135	-78	25	32
	Large (10)	14.1	E	137	-69	31	28	137	-70	25	32	138	-72	26	32
			M	140	-66	30	28	140	-72	28	30	140	-72	28	30
			O	140	-71	30	28	140	-71	29	29	140	-71	29	29
Medium (13.0)	Small (0.2)	1.6	E	142	3	36	17	81	-23	11	13	97	-197	12	22
			M	141	-3	36	17	112	-35	15	19	87	-137	16	24
			O	142	-26	36	18	135	-49	20	25	109	-170	18	34
	Medium (1.7)	2.8	E	145	7	37	17	104	-33	18	18	97	-135	19	22
			M	144	8	38	16	128	-43	22	22	102	-237	20	35
			O	144	-19	37	16	141	-55	25	27	104	-235	23	35
	Large (10)	4.3	E	142	-10	37	17	127	-44	22	23	129	-218	22	30
			M	144	-5	38	16	142	-49	27	24	134	-233	24	37
			O	142	-24	37	17	144	-59	30	26	135	-229	24	43
Deep (24.0)	Small (0.2)	0.9	E	141	2	37	15	60	-12	8	8	45	-107	9	12
			M	141	1	37	17	89	-19	13	12	56	-89	13	18
			O	141	0	39	17	130	-19	18	16	111	-104	18	36
	Medium (1.7)	1.5	E	148	2	38	16	99	-17	15	13	80	-131	12	24
			M	149	2	39	16	119	-21	19	15	84	-118	13	31
			O	154	2	39	14	150	-26	26	18	129	-123	20	46
	Large (10)	2.3	E	157	5	40	15	117	-18	22	17	125	-128	17	36
			M	158	7	40	17	144	-23	27	19	131	-133	19	47
			O	160	7	40	17	161	-29	33	21	95	-118	10	53

Note: H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively.

[1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 24a. Number of locations (out of 209) having winterkill, summerkill, and with suitable habitat for cold-water, cool-water and warmwater fish under past and projected $2xCO_2$ climate scenarios in 27 lake types over the contiguous U.S.

Lake Characteristics				Cold-Water Fish			Cool-water Fish			Warmwater Fish		
				Number of Locations for			Number of Locations for			Number of Locations for		
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Winterkill	Summerkill	Habitat	Winterkill	Summerkill	Habitat	Winterkill	Summerkill	Habitat
Shallow (4.0)	Small (0.2)	5.3	E	18(0)	126(201)	65(8)	18(0)	15(66)	176(143)	17(0)	0	192(209)
			M	7(0)	175(205)	27(4)	7(0)	23(76)	179(133)	5(0)	0	204(209)
			O	0	191(206)	18(3)	0	36(96)	173(113)	0	0	209
	Medium (1.7)	9.0	E	29(0)	123(198)	57(11)	29(0)	5(58)	175(151)	25(0)	0	184(209)
			M	14(0)	167(205)	28(4)	14(0)	19(72)	176(137)	13(0)	0	196(209)
			O	0	186(205)	23(4)	0	23(85)	186(124)	0	0	209
	Large (10)	14.1	E	30(0)	151(204)	28(5)	30(0)	10(67)	169(142)	27(0)	0	182(209)
			M	14(0)	170(205)	25(4)	14(0)	16(71)	179(138)	13(0)	0	196(209)
			O	0	180(205)	29(4)	0	19(77)	190(132)	0	0	209
Medium (13.0)	Small (0.2)	1.6	E	0	90(181)	119(28)	0	1(37)	208(172)	0	0	209
			M	0	87(180)	122(29)	0	2(42)	207(167)	0	0	209
			O	0	81(172)	128(37)	0	3(50)	206(159)	0	0	209
	Medium (1.7)	2.8	E	0	93(184)	116(25)	0	0(37)	209(172)	0	0	209
			M	0	91(184)	118(25)	0	0(38)	209(171)	0	0	209
			O	0	94(188)	115(21)	0	2(47)	207(162)	0	0	209
	Large (10)	4.3	E	0	102(188)	107(21)	0	1(45)	208(164)	0	0	209
			M	0	102(188)	107(21)	0	1(42)	208(167)	0	0	209
			O	0	111(192)	98(17)	0	1(47)	208(162)	0	0	209
Deep (24.0)	Small (0.2)	0.9	E	0	69(157)	140(52)	0	0(8)	209(201)	0	0	209
			M	0	35(89)	174(120)	0	0(4)	209(205)	0	0	209
			O	0	6(23)	203(186)	0	0(1)	209(208)	0	0	209
	Medium (1.7)	1.5	E	0	67(159)	142(50)	0	0(19)	209(190)	0	0	209
			M	0	53(127)	156(82)	0	0(7)	209(202)	0	0	209
			O	0	17(49)	192(160)	0	0(1)	209(208)	0	0	209
	Large (10)	2.3	E	0	69(163)	140(46)	0	0(17)	209(192)	0	0	209
			M	0	61(136)	148(73)	0	0(8)	209(201)	0	0	209
			O	0	39(95)	170(114)	0	0(2)	209(207)	0	0	209

Note: Numbers **outside** and **inside** parentheses were simulated for **past** climate and a **$2xCO_2$** climate scenario, respectively, **or** one number for both climate scenarios. H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively. [1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Table 24b. Number of locations (out of 209) with cold-water, cool-water and warmwater fish habitat changes between projected $2xCO_2$ and past climate scenarios in 27 lake types over the contiguous U.S.

Lake Characteristics				**Cold-Water Fish**			**Cool-water Fish**			**Warmwater Fish**		
H_{MAX} (m)	A_S (km^2)	Geometry ratio [1]	Z_S	Number of Locations for			Number of Locations for			Number of Locations for		
				Case A	Case B	Case C	Case A	Case B	Case C	Case A	Case B	Case C
Shallow (4.0)	Small (0.2)	5.3	E	14	4	61	0	18	51	0	17	0
			M	7	0	23	0	7	53	0	5	0
			O	0	0	15	0	0	60	0	0	0
	Medium (1.7)	9.0	E	26	3	49	0	29	53	0	25	0
			M	14	0	24	0	14	53	0	13	0
			O	0	0	19	0	0	62	0	0	0
	Large (10)	14.1	E	30	0	23	0	30	57	0	17	0
			M	14	0	21	0	14	55	0	13	0
			O	0	0	25	0	0	58	0	0	0
Medium (13.0)	Small (0.2)	1.6	E	0	0	91	0	0	36	0	0	0
			M	0	0	93	0	0	40	0	0	0
			O	0	0	91	0	0	47	0	0	0
	Medium (1.7)	2.8	E	0	0	91	0	0	37	0	0	0
			M	0	0	93	0	0	38	0	0	0
			O	0	0	94	0	0	45	0	0	0
	Large (10)	4.3	E	0	0	86	0	0	44	0	0	0
			M	0	0	86	0	0	41	0	0	0
			O	0	0	81	0	0	46	0	0	0
Deep (24.0)	Small (0.2)	0.9	E	0	0	88	0	0	8	0	0	0
			M	0	0	54	0	0	4	0	0	0
			O	0	0	17	0	0	1	0	0	0
	Medium (1.7)	1.5	E	0	0	92	0	0	19	0	0	0
			M	0	0	74	0	0	7	0	0	0
			O	0	0	32	0	0	1	0	0	0
	Large (10)	2.3	E	0	0	94	0	0	17	0	0	0
			M	0	0	75	0	0	8	0	0	0
			O	0	0	56	0	0	2	0	0	0

Note: Case A, Case B and Case C are designated in Table 18 for "from winterkill to summerkill", "from winterkill to habitat", and "from habitat to summerkill", respectively. H_{MAX}, A_S, and Z_S stand for maximum depth, surface area, trophic state (E - Eutrophic, M - Mesotrophic, O - Oligotrophic), respectively. [1] - Geometry ratio is defined as $A_S^{0.25}/H_{MAX}$ ($m^{-0.5}$).

Figures 1 through 50

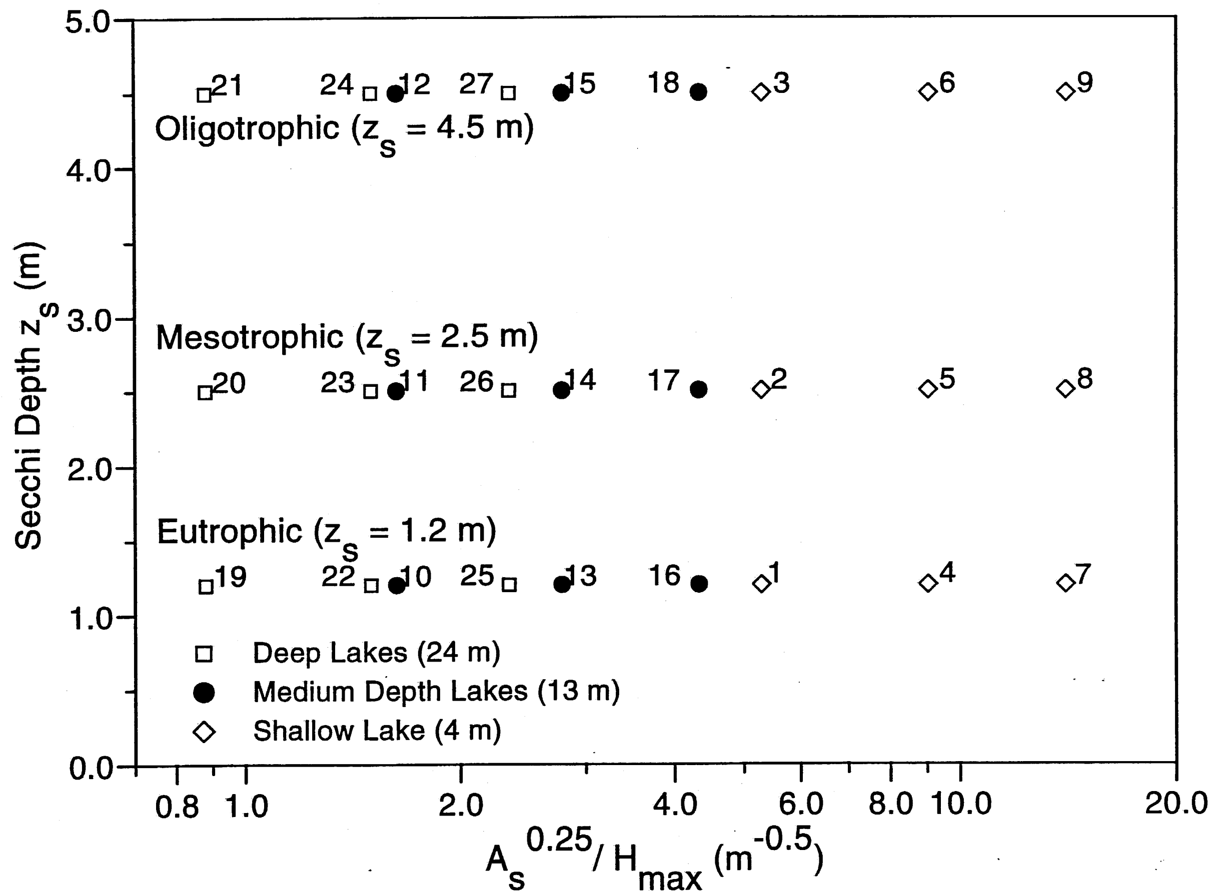

Fig. 1 Distribution of 27 lake types on a plot with the geometry ratio $A_S^{0.25}/H_{MAX}$ as abscissa and Secchi depth z_S as ordinate. The numbers are lake type numbers corresponding to Table 1.

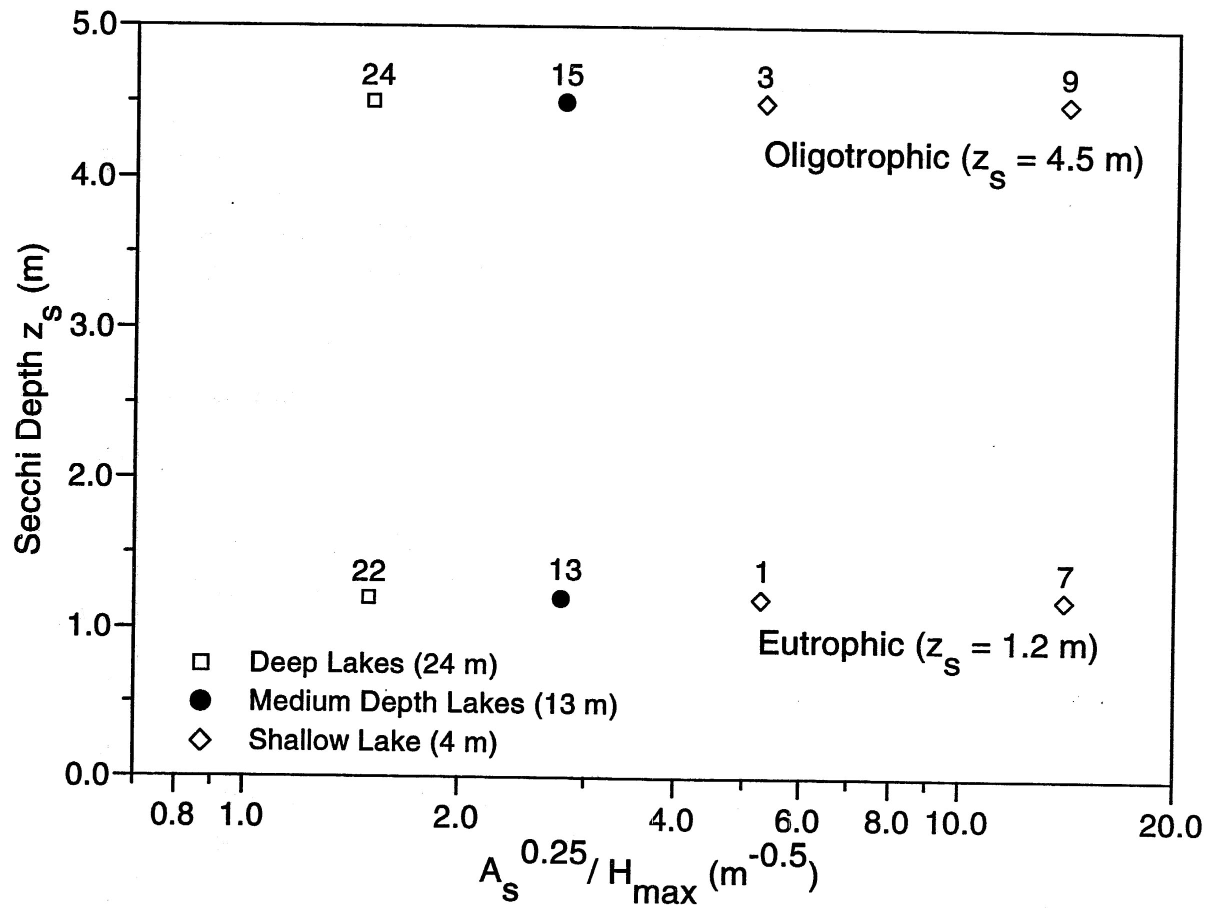

Fig. 1 (modified) Distribution of 8 lake types on a plot with the geometry ratio $A_S^{0.25}/H_{MAX}$ as abscissa and Secchi depth z_S as ordinate. The numbers are lake type numbers corresponding to Table 1.

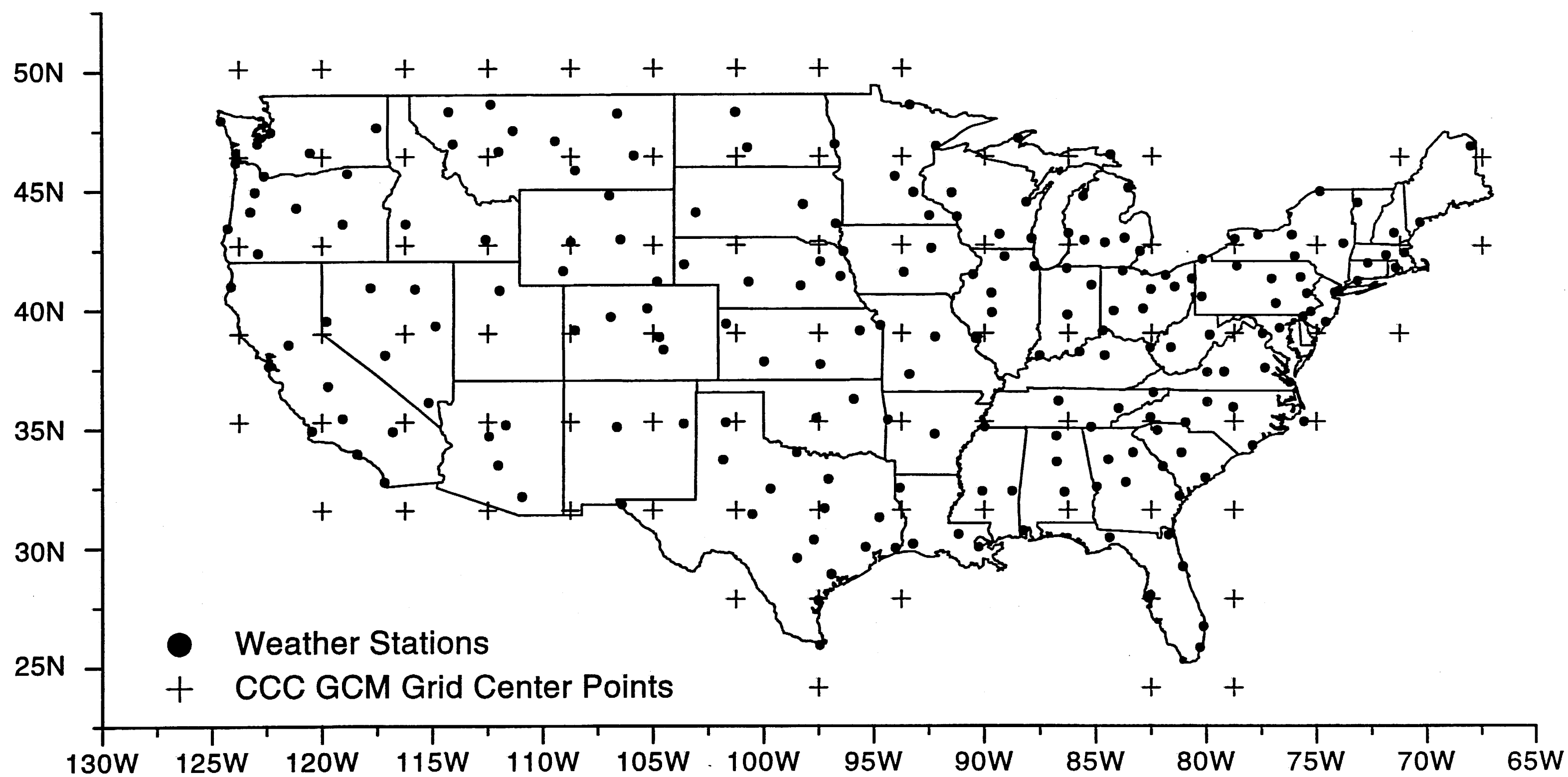

Fig. 2 Locations of 209 weather stations and grid center points of the $2xCO_2$ CCC GCM used in the continental-scale simulations.

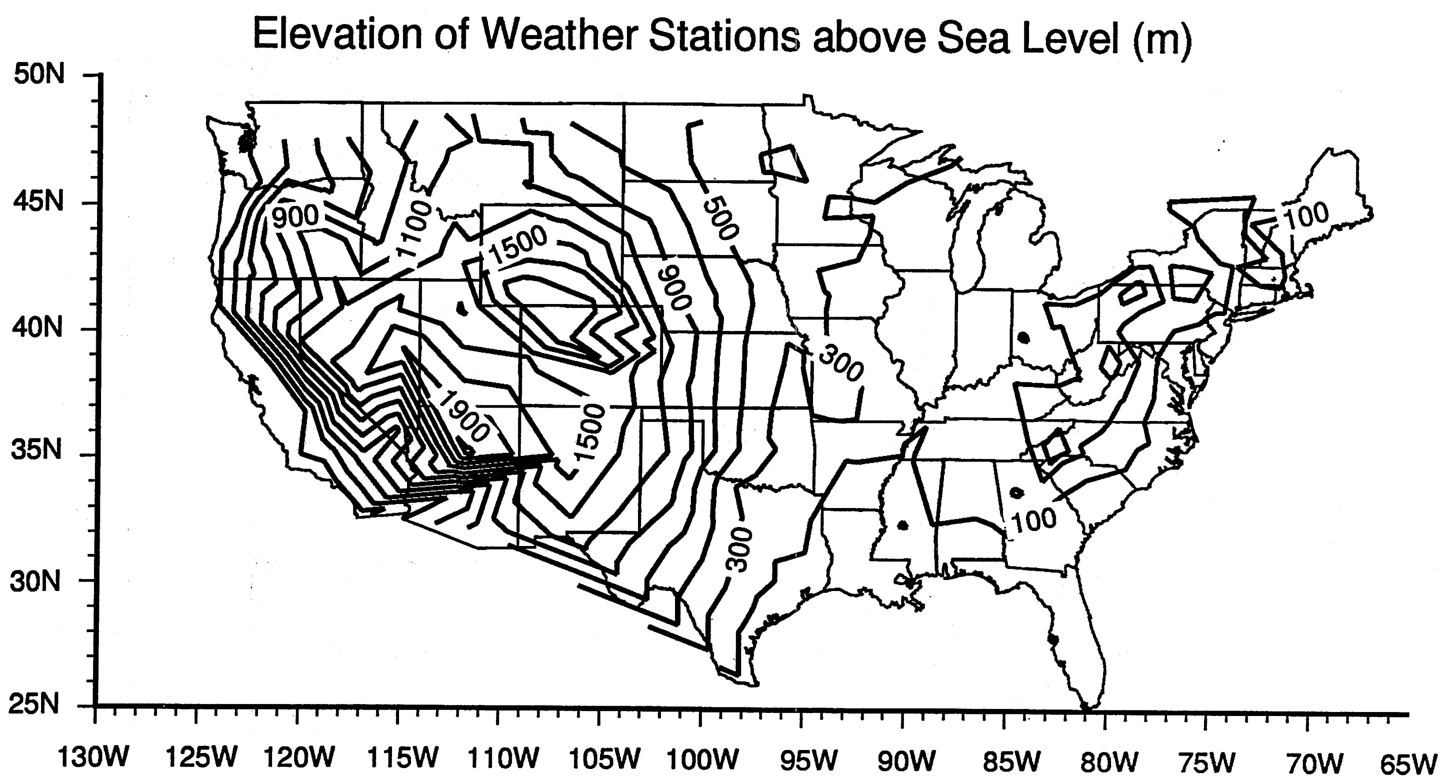

Fig. 3 Elevations (m) above mean sea level for 209 weather stations used.

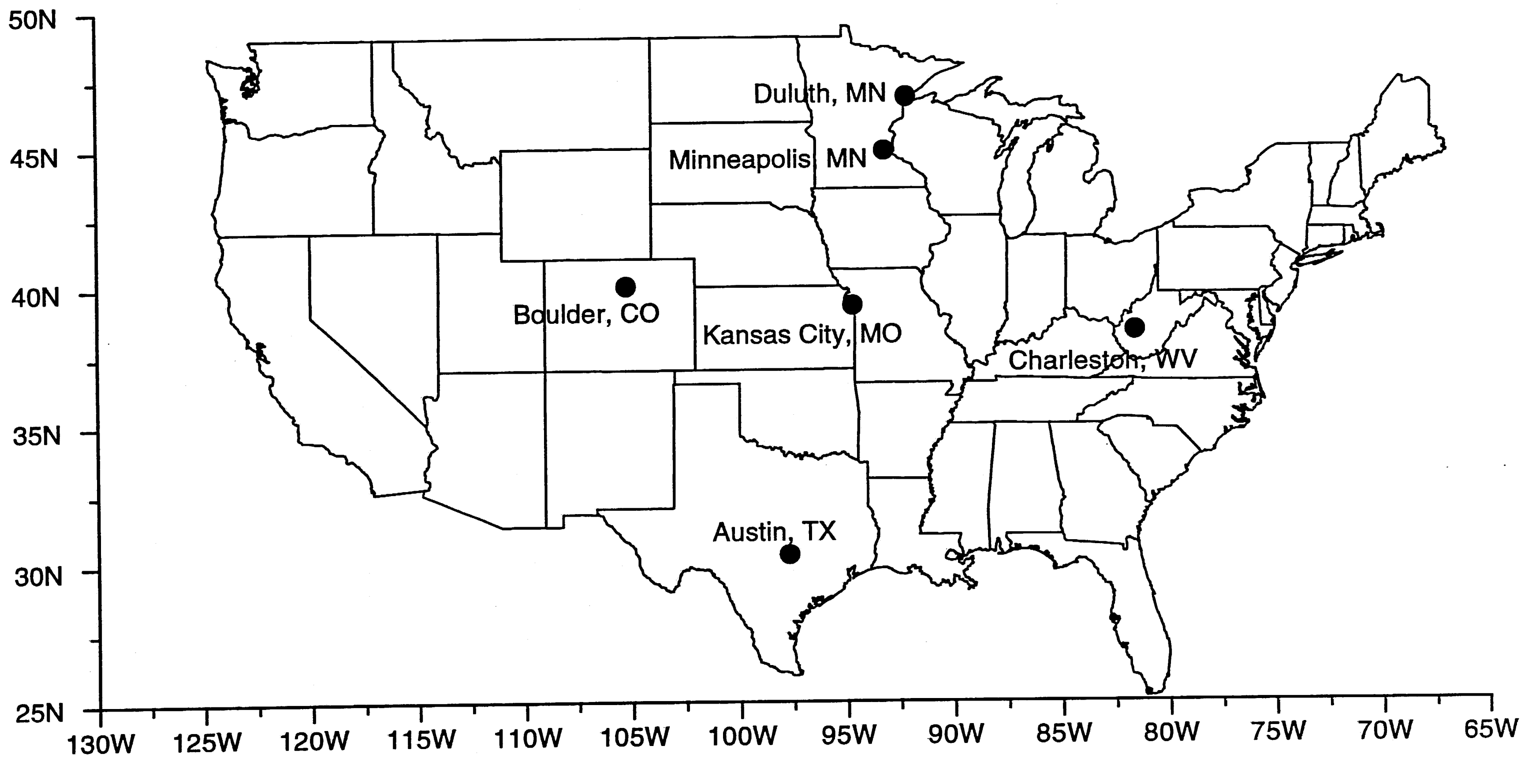

Fig. 4 Geographic locations of selected weather stations during the analysis.

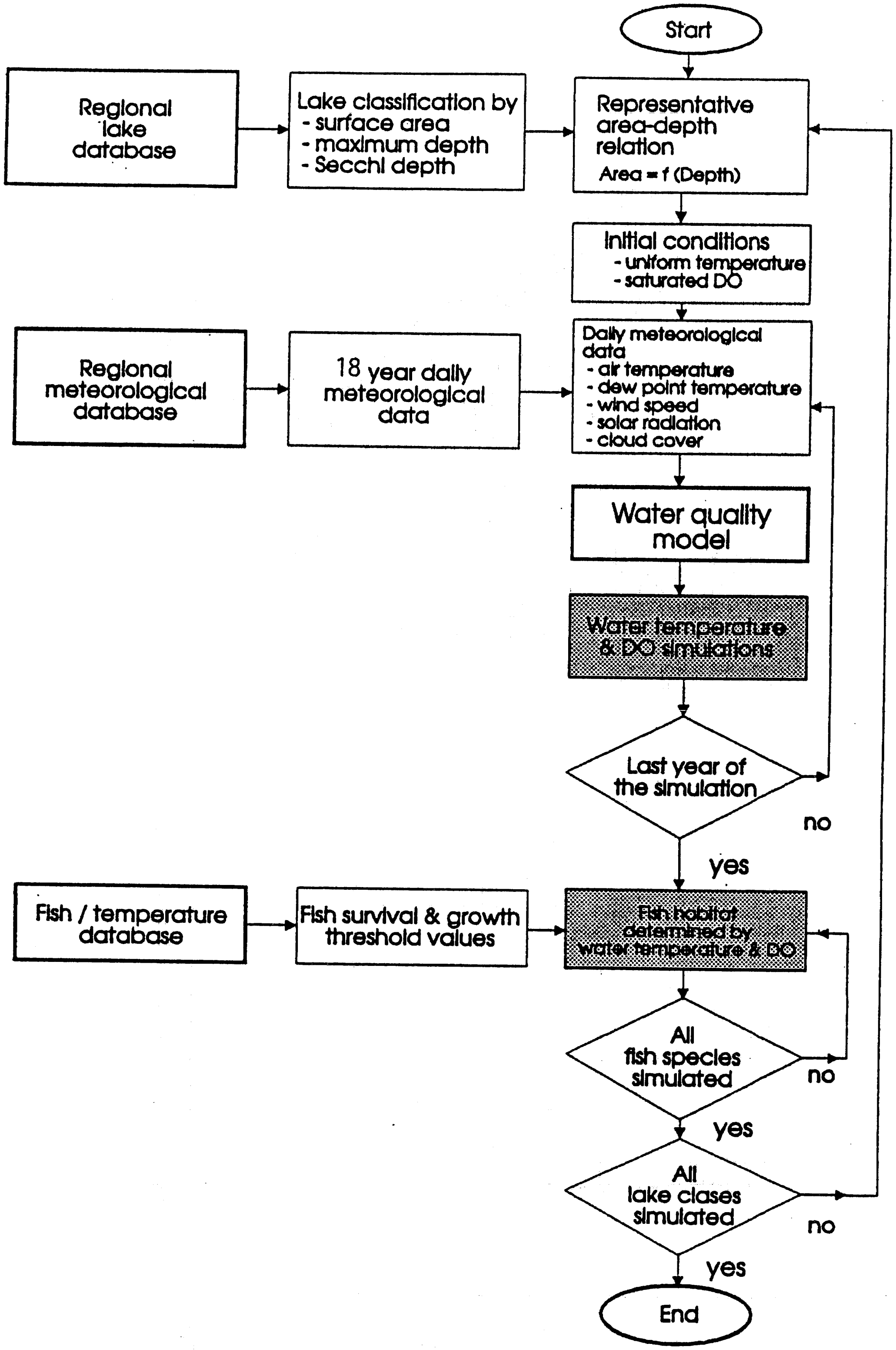

Fig. 5 Schematic of the simulation procedures for water temperature, dissolved oxygen concentration, and fish habitat (from Stefan et al., 1994).

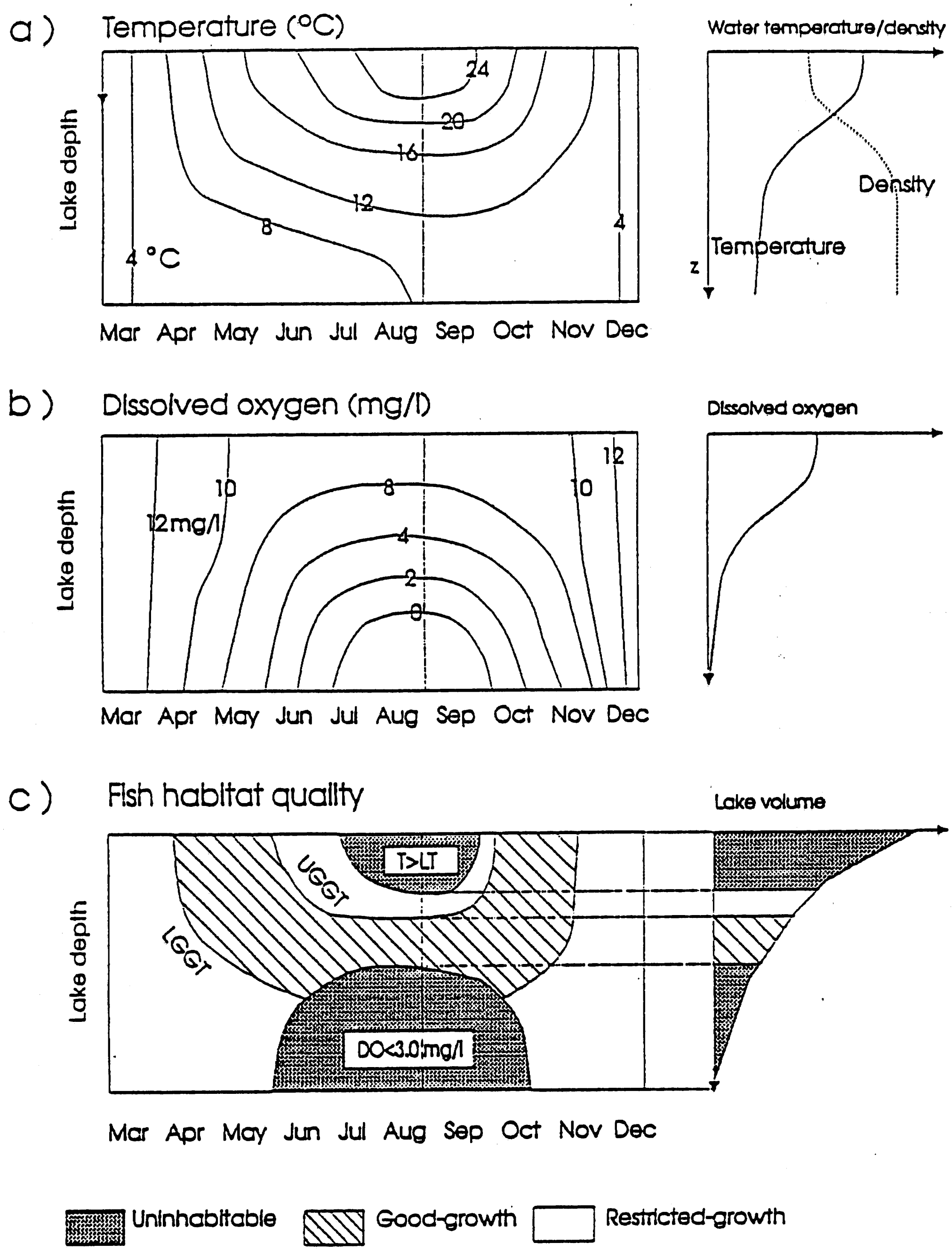

Fig. 6a Distribution over time and depth of (a) water temperature (T) isotherms (°C), (b) dissolved oxygen (DO) isopleths (mg/l), and (c) those isotherms and DO isopleths which are considered for the survival and growth of a fish species, in a seasonally stratified lake (from Hondzo and Stefan, 1996).

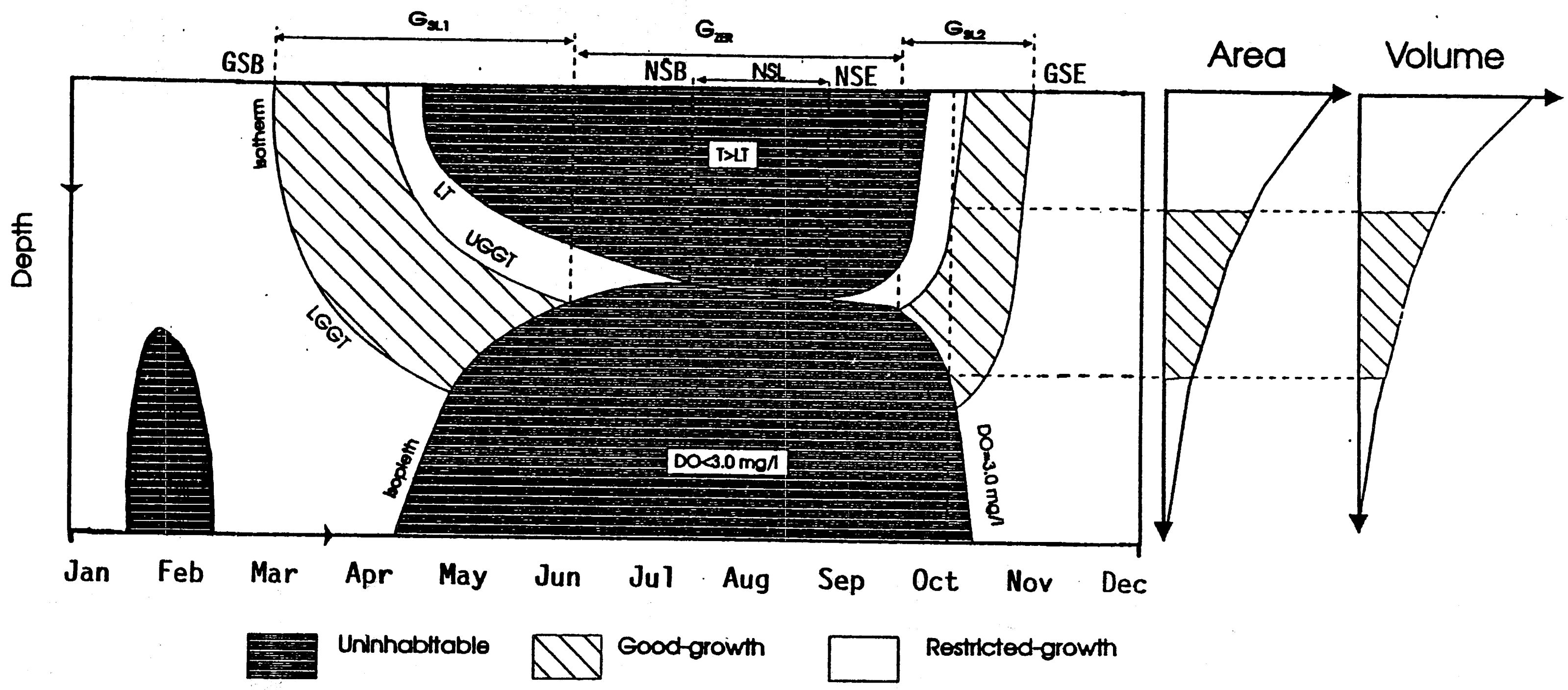

Fig. 6b Distribution over time and depth of those isotherms and dissolved oxygen isopleths which are considered for the survival and growth of a fish species, in a seasonally stratified lake **where fish can not be present.** Fish survival and good-growth parameters defined are shown (after Hondzo and Stefan, 1996).

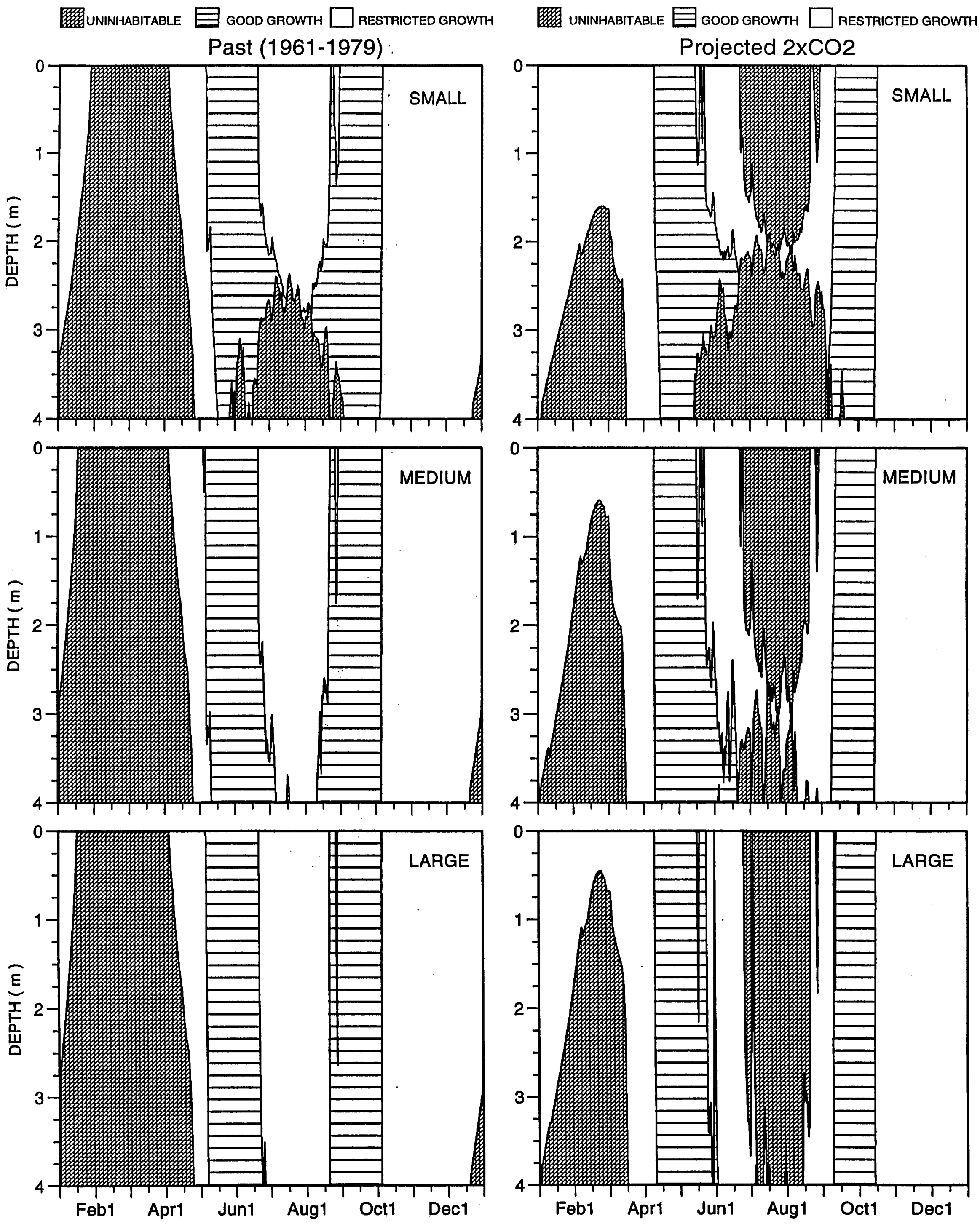

Figure 7a. Depth-time contours of **cold-water** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Duluth, MN,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

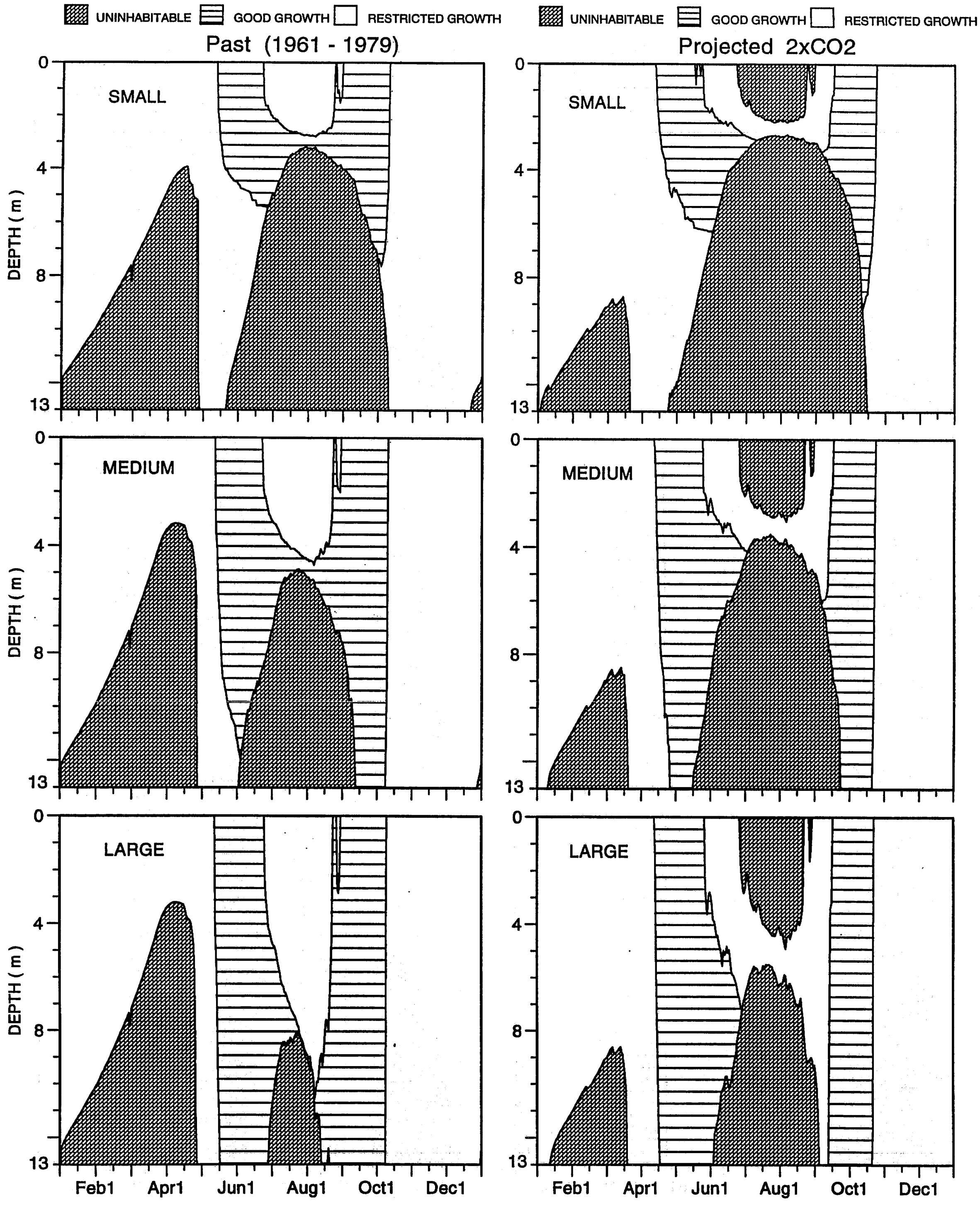

Figure 7b. Depth-time contours of **cold-water** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

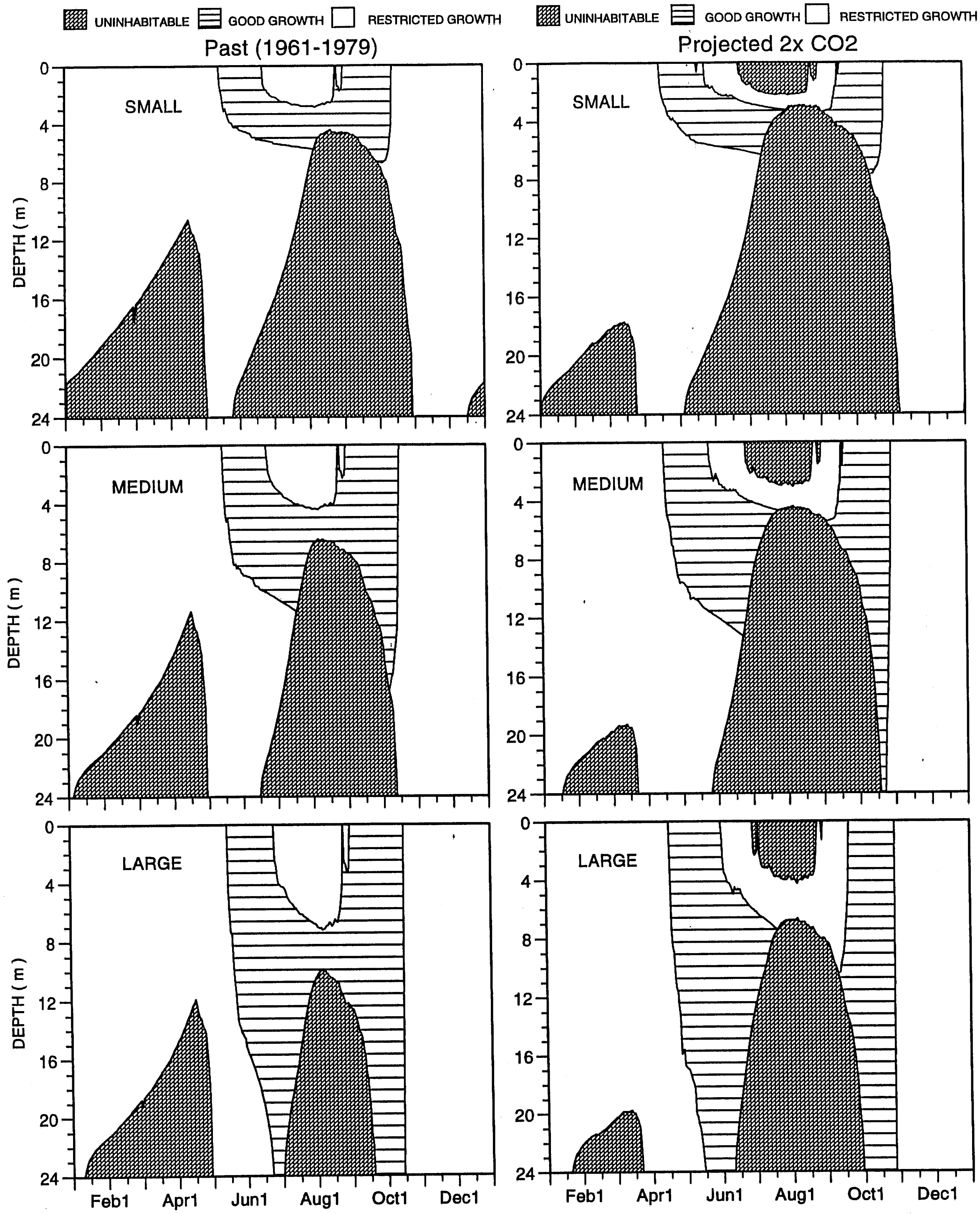

Figure 7c. Depth-time contours of **cold-water** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

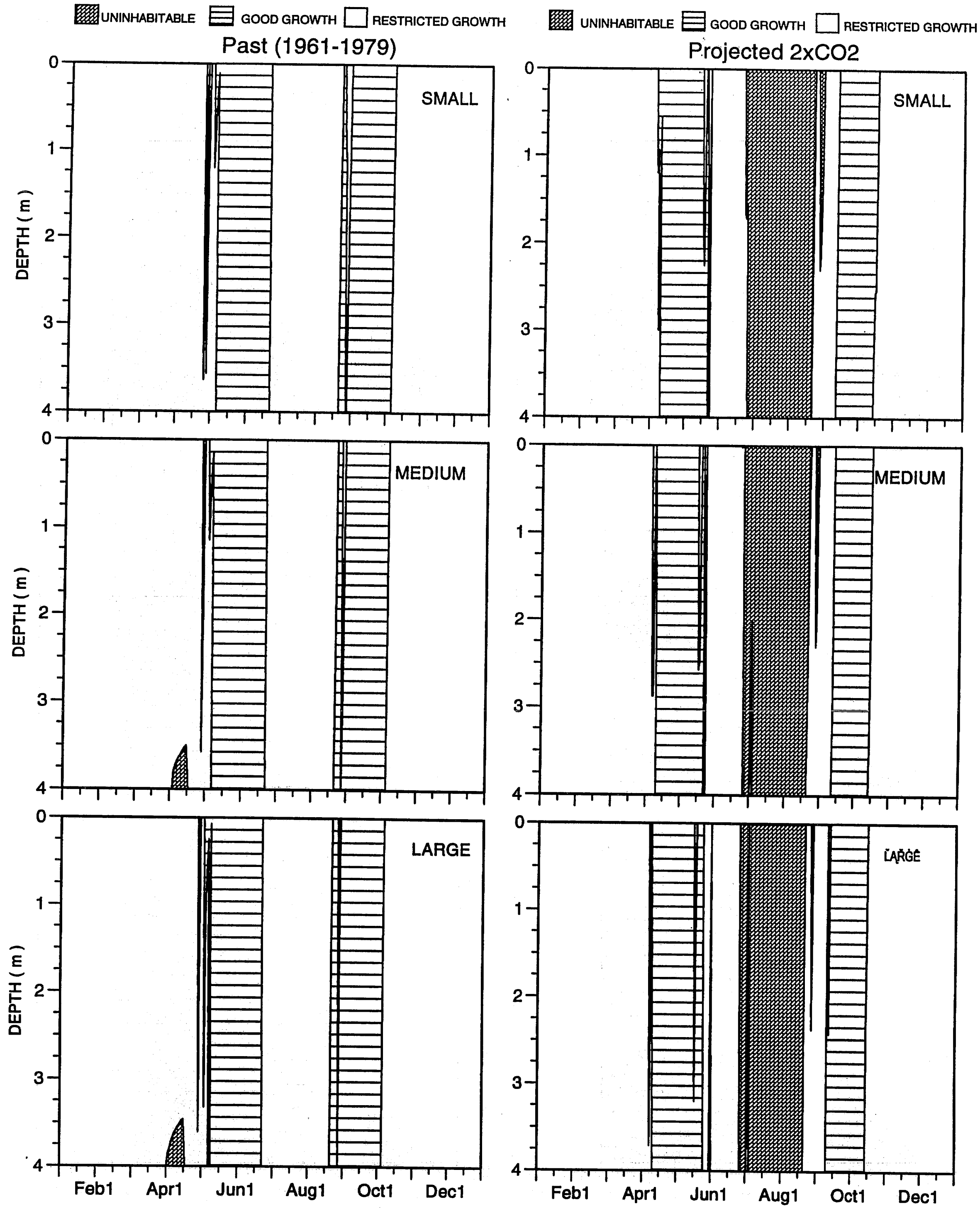

Figure 7d. Depth-time contours of **cold-water** fish habitats in **shallow** (4.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

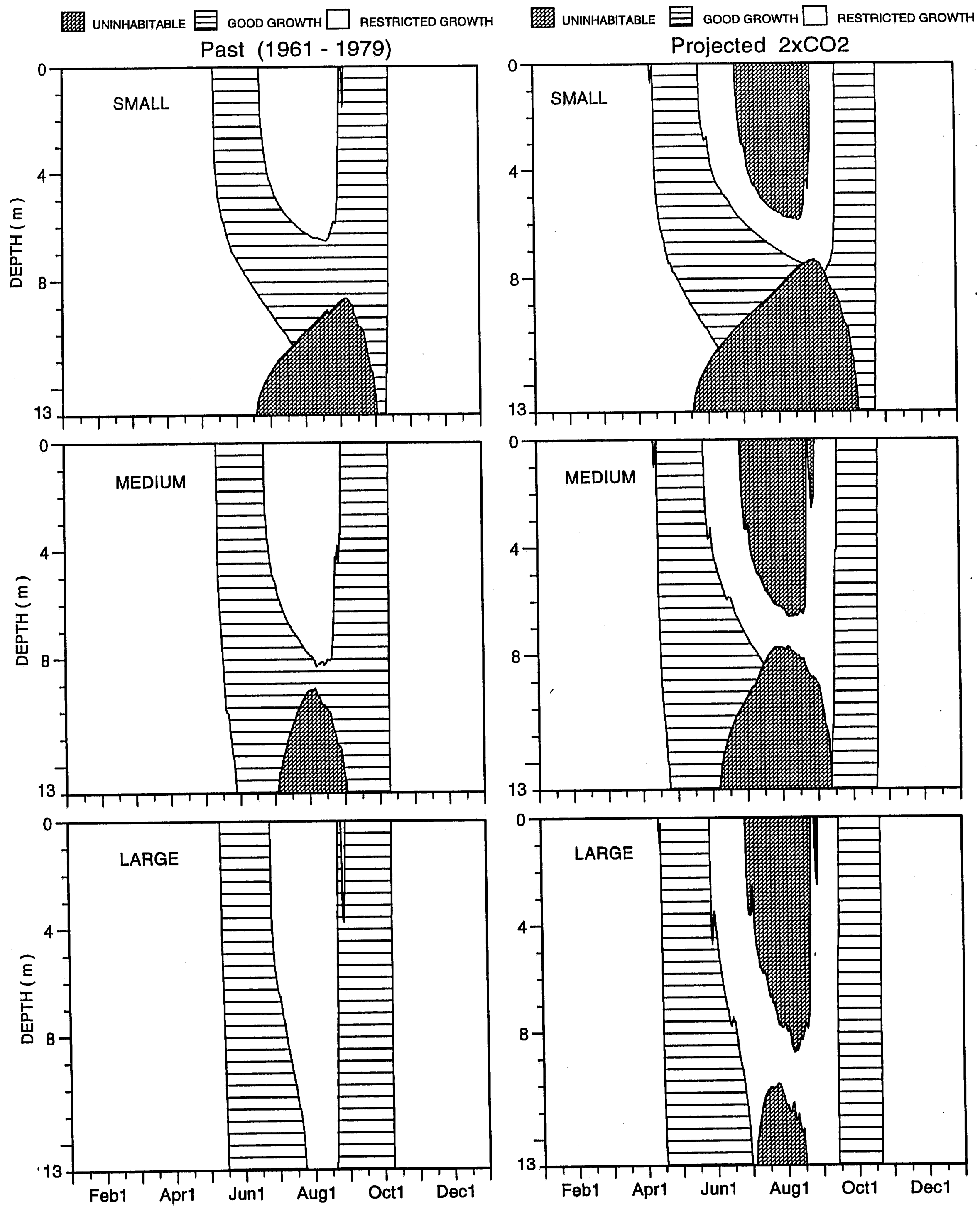

Figure 7e. Depth-time contours of **cold-water** fish habitats in **medium depth** (13.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

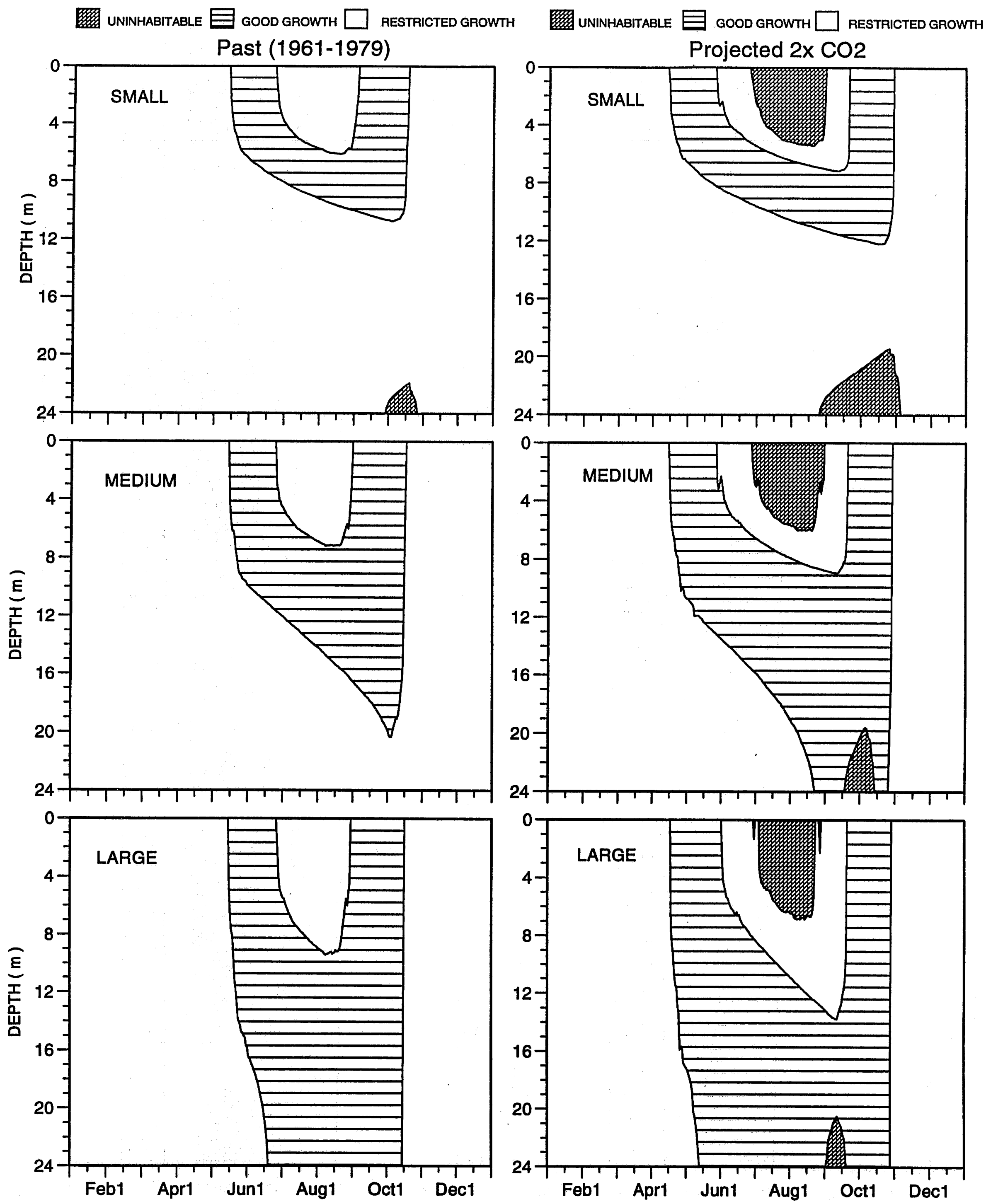

Figure 7f. Depth-time contours of **cold-water** fish habitats in **deep** (24.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

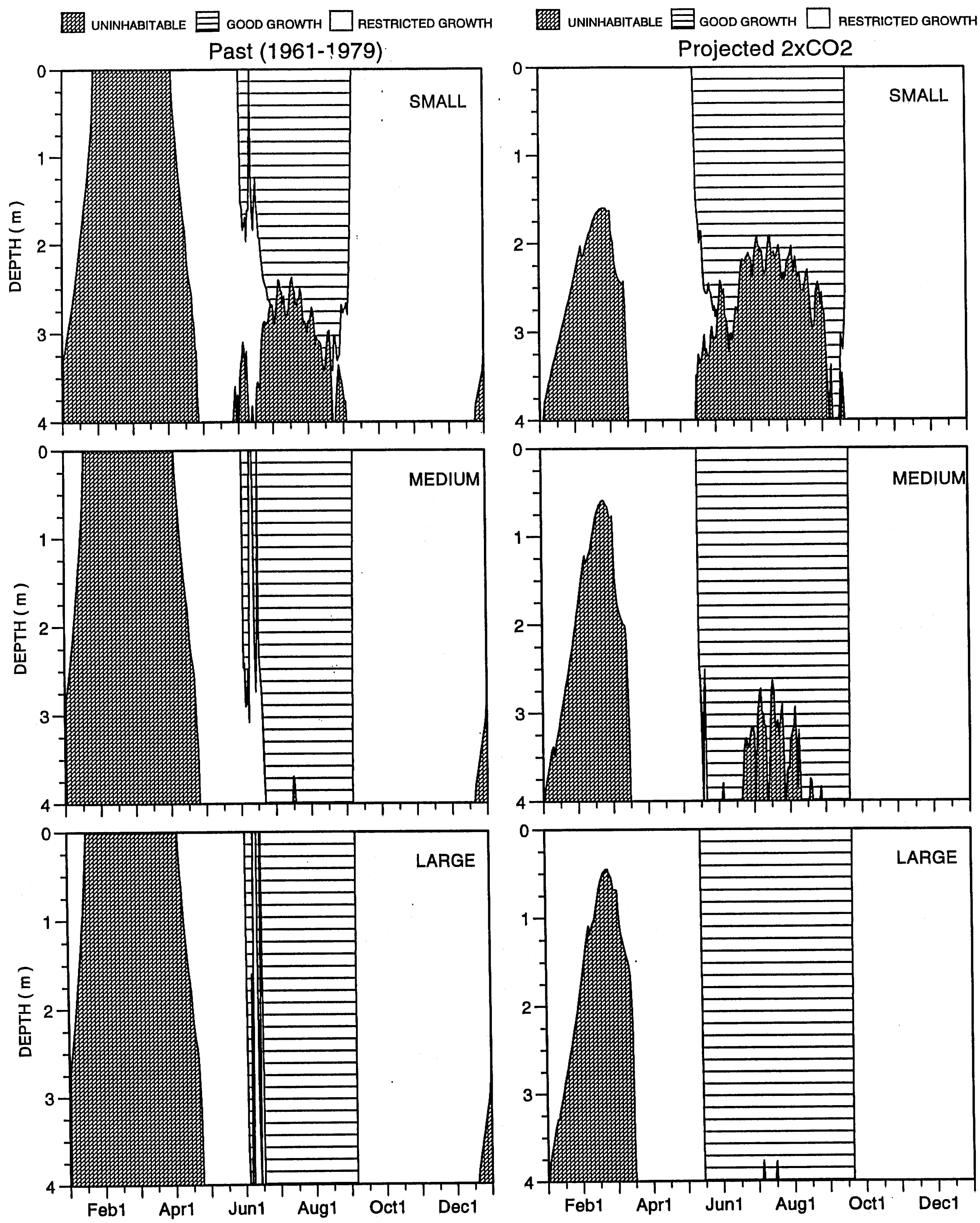

Figure 8a. Depth-time contours of **cool-water** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

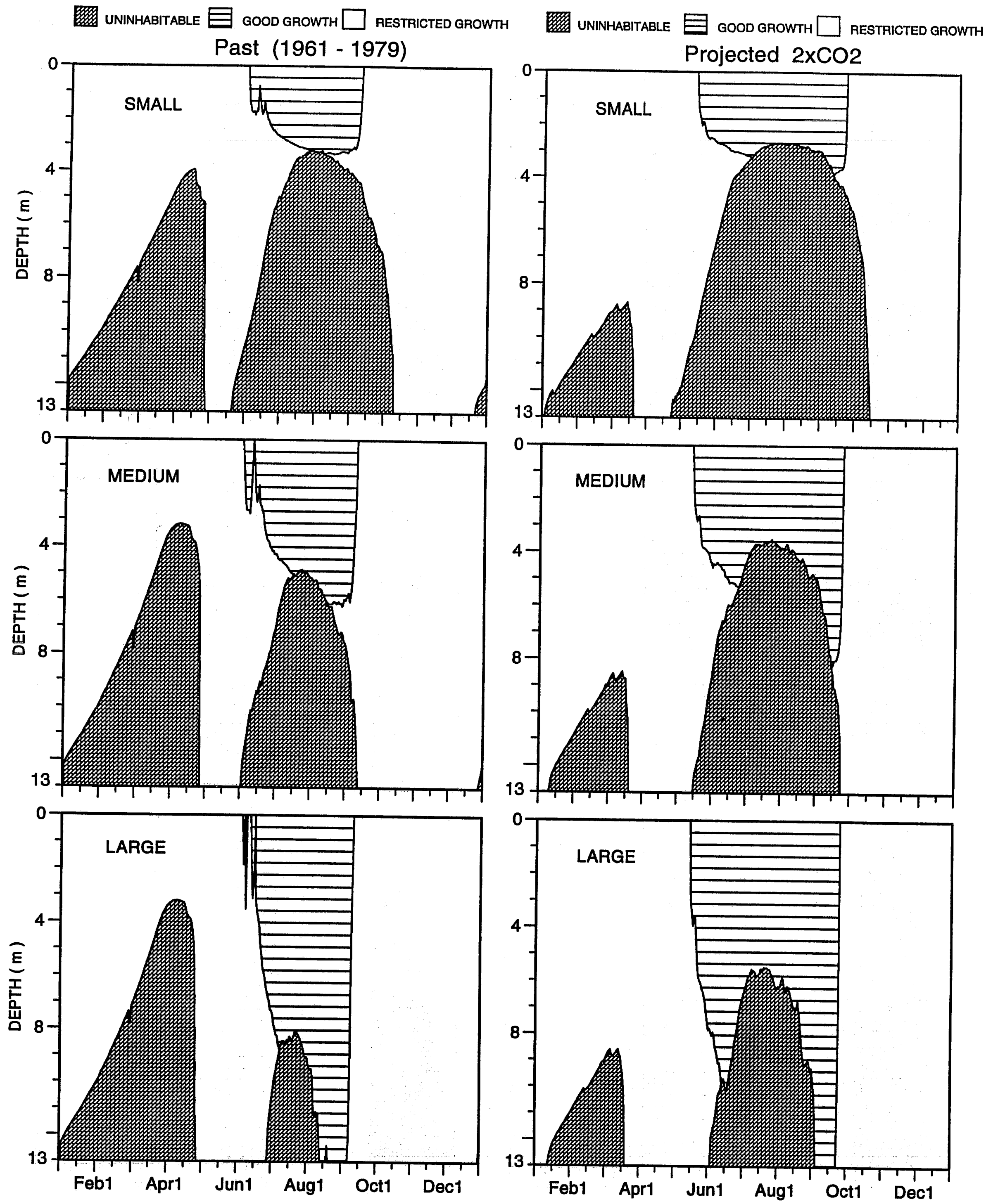

Figure 8b. Depth-time contours of **cool-water** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

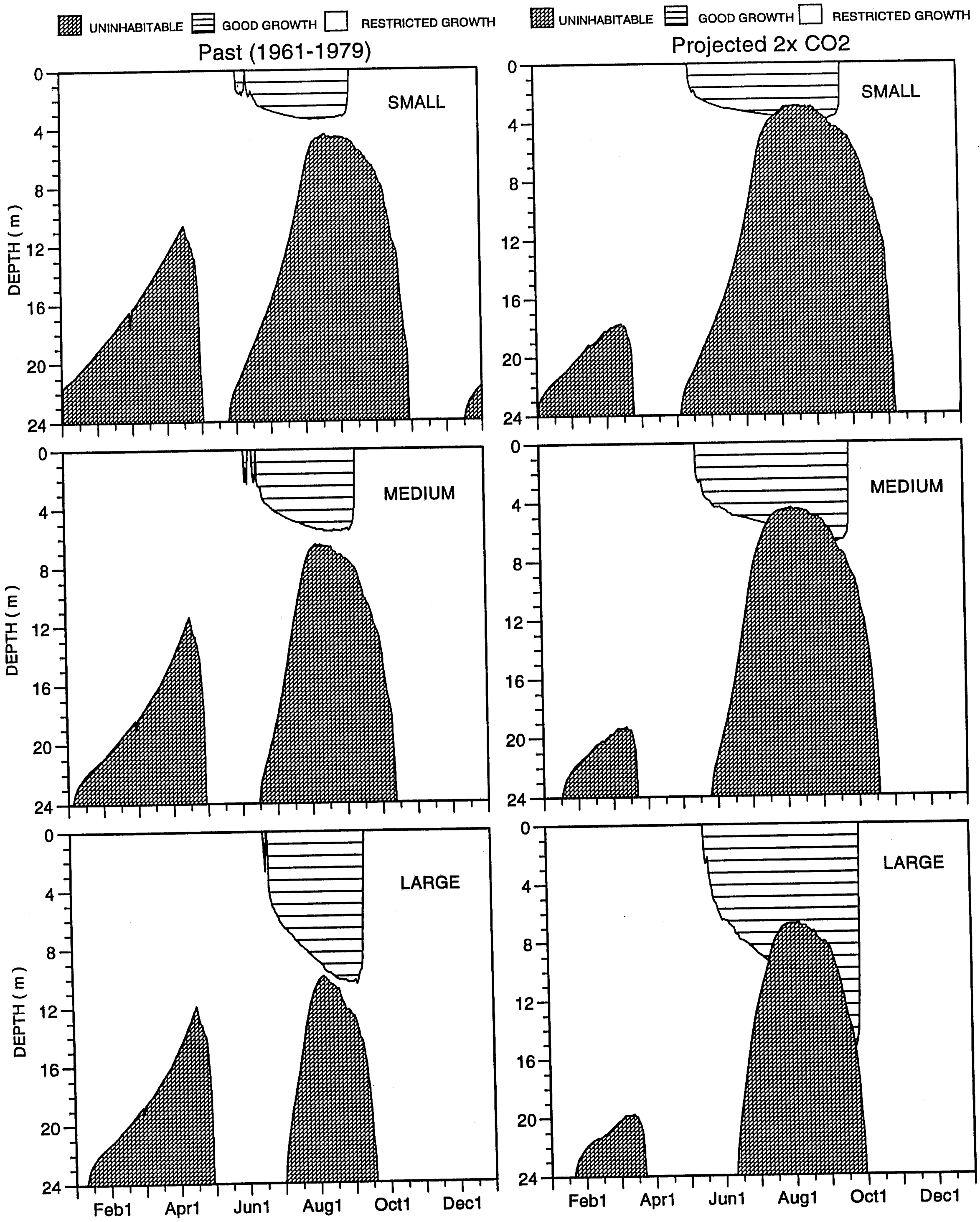

Figure 8c. Depth-time contours of **cool-water** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Duluth, MN,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

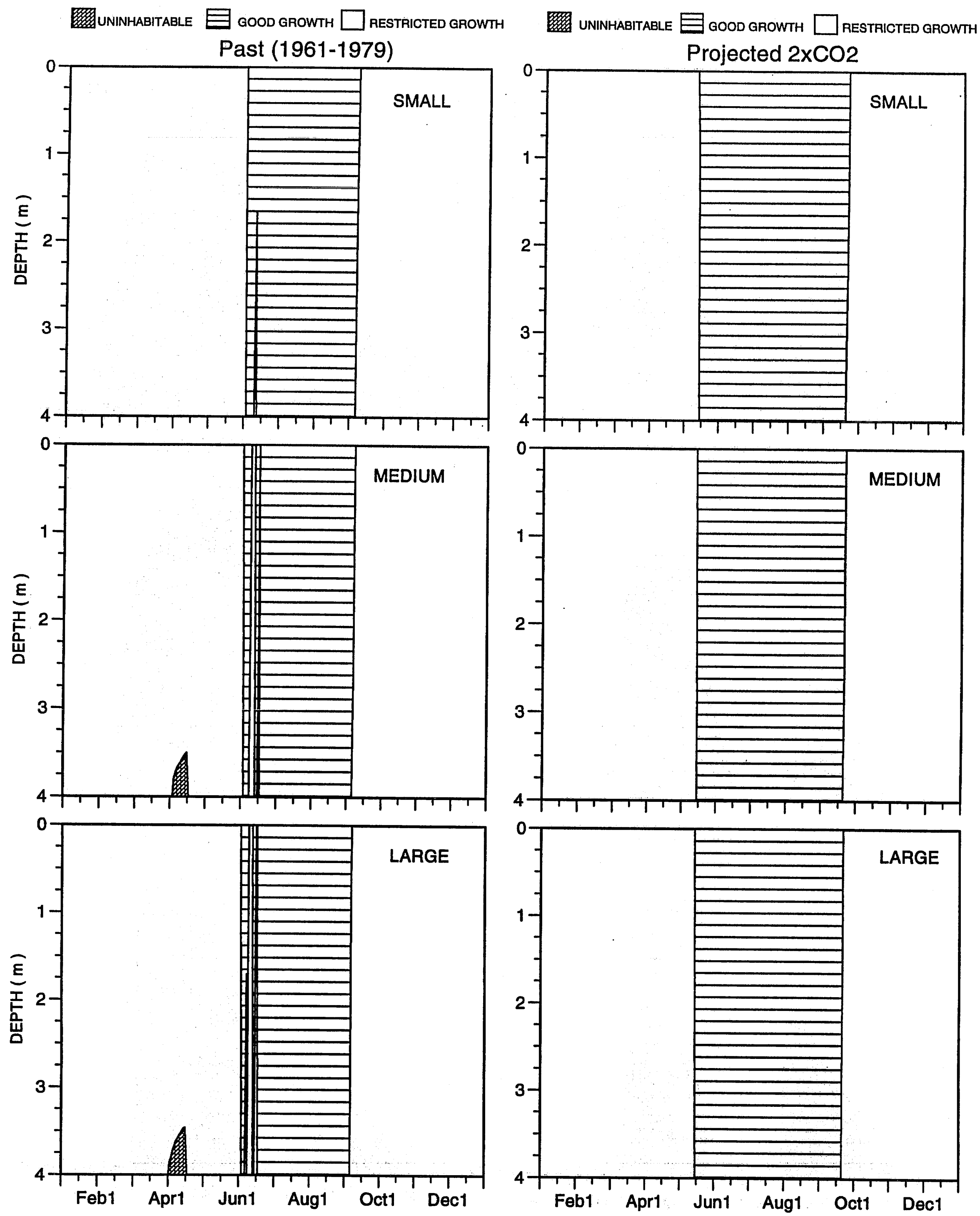

Figure 8d. Depth-time contours of **cool-water** fish habitats in **shallow** (4.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

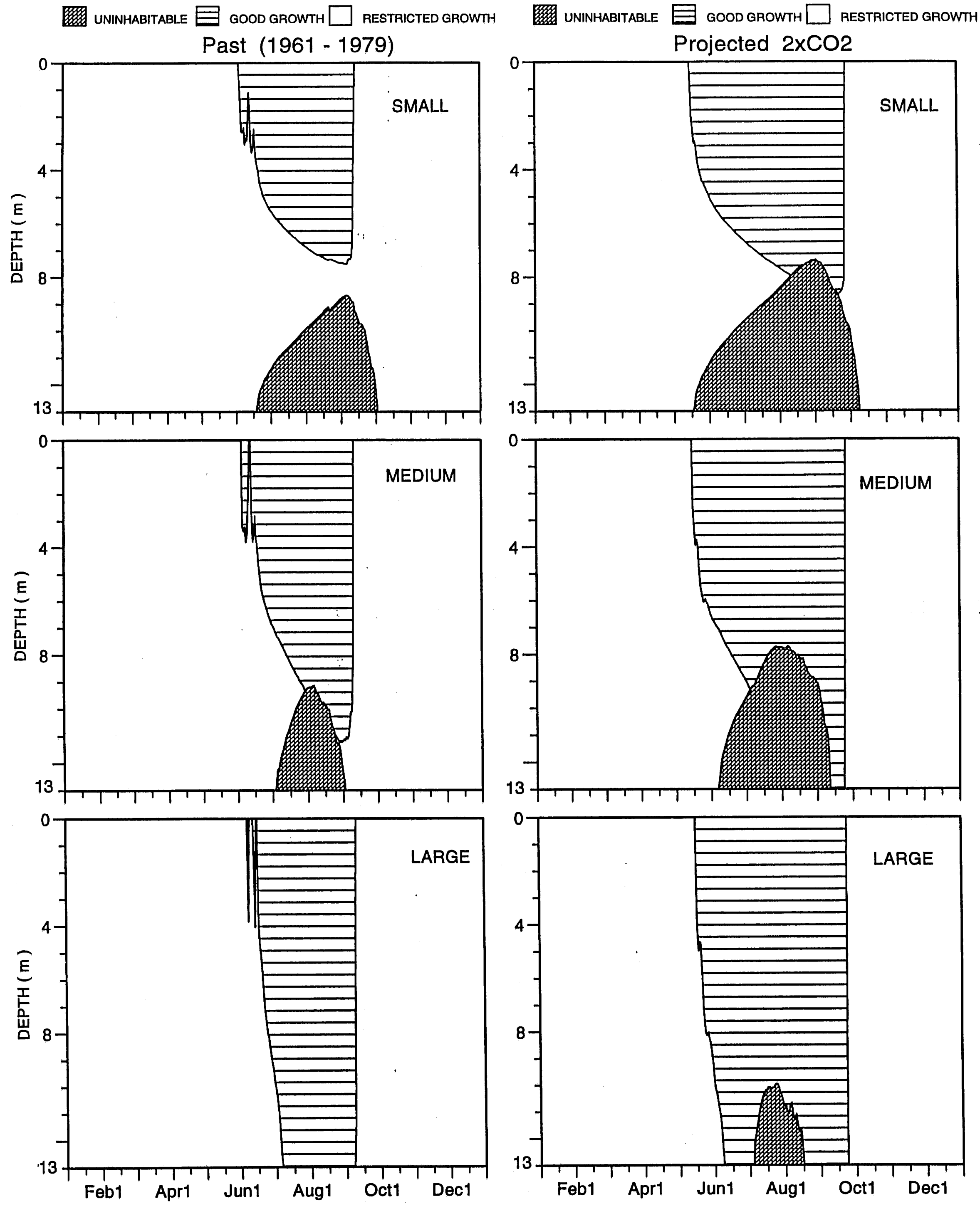

Figure 8e. Depth-time contours of **cool-water** fish habitats in **medium depth** (13.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

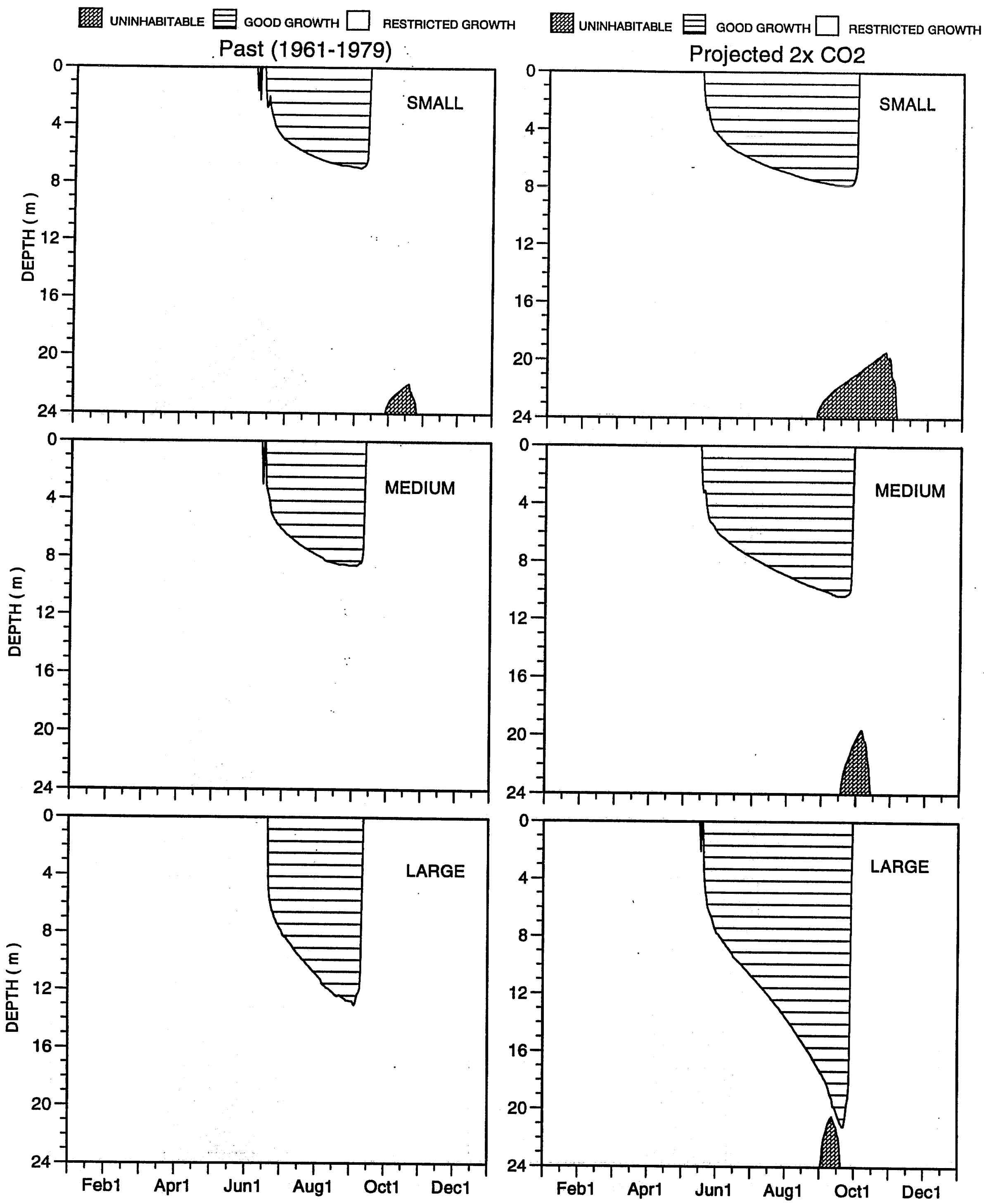

Figure 8f. Depth-time contours of **cool-water** fish habitats in **deep** (24.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

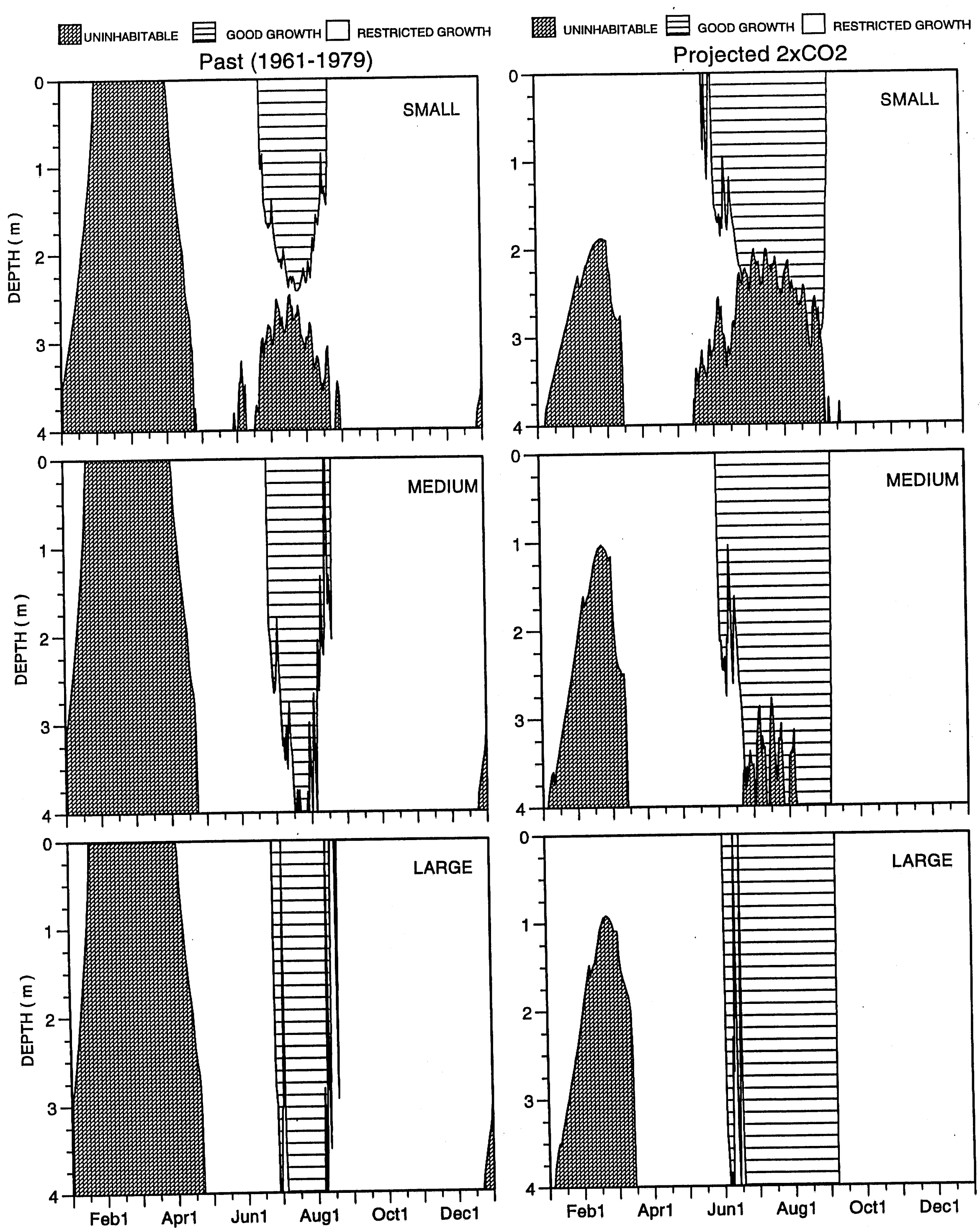

Figure 9a. Depth-time contours of **warm-water** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

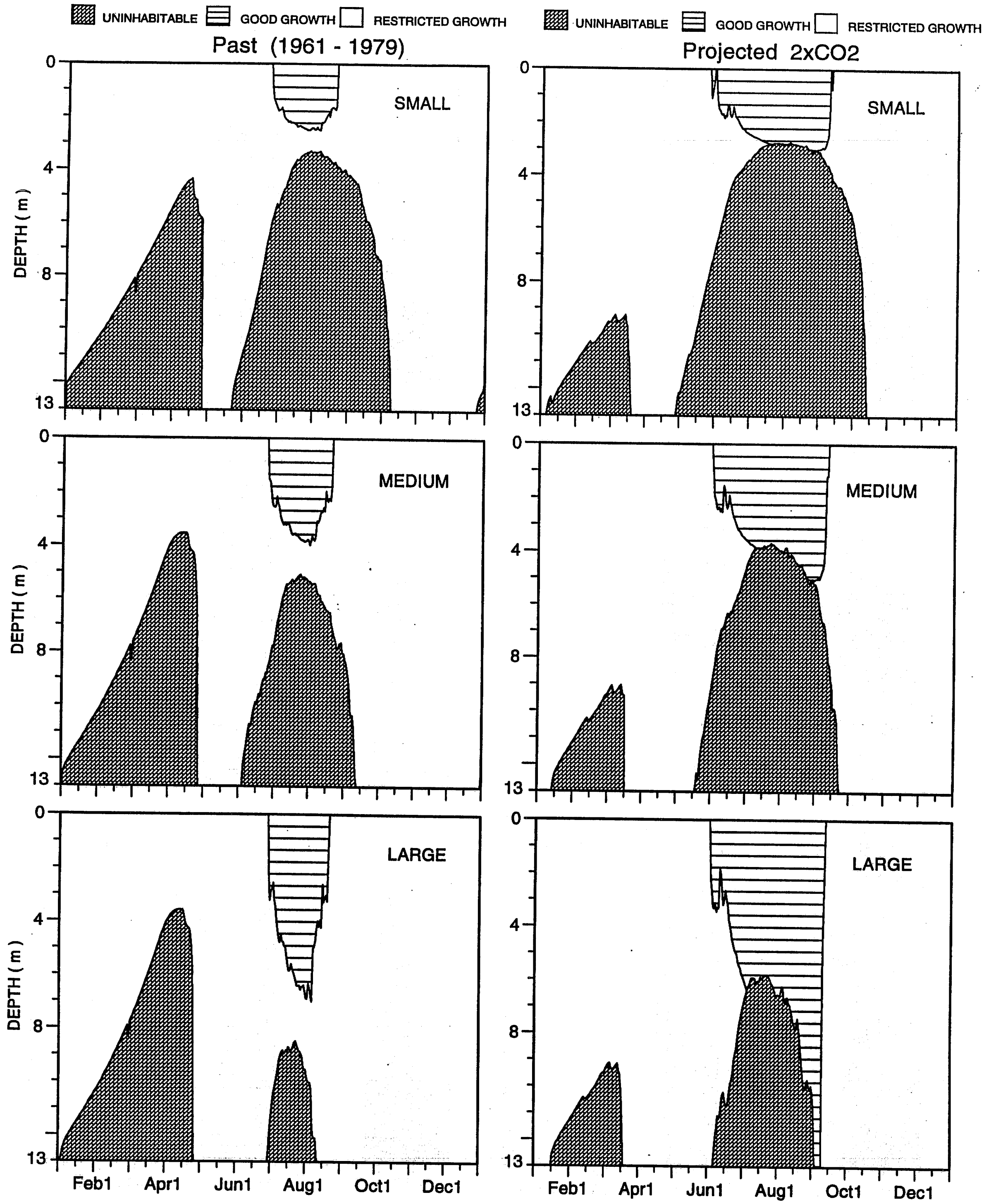

Figure 9b. Depth-time contours of **warm-water** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

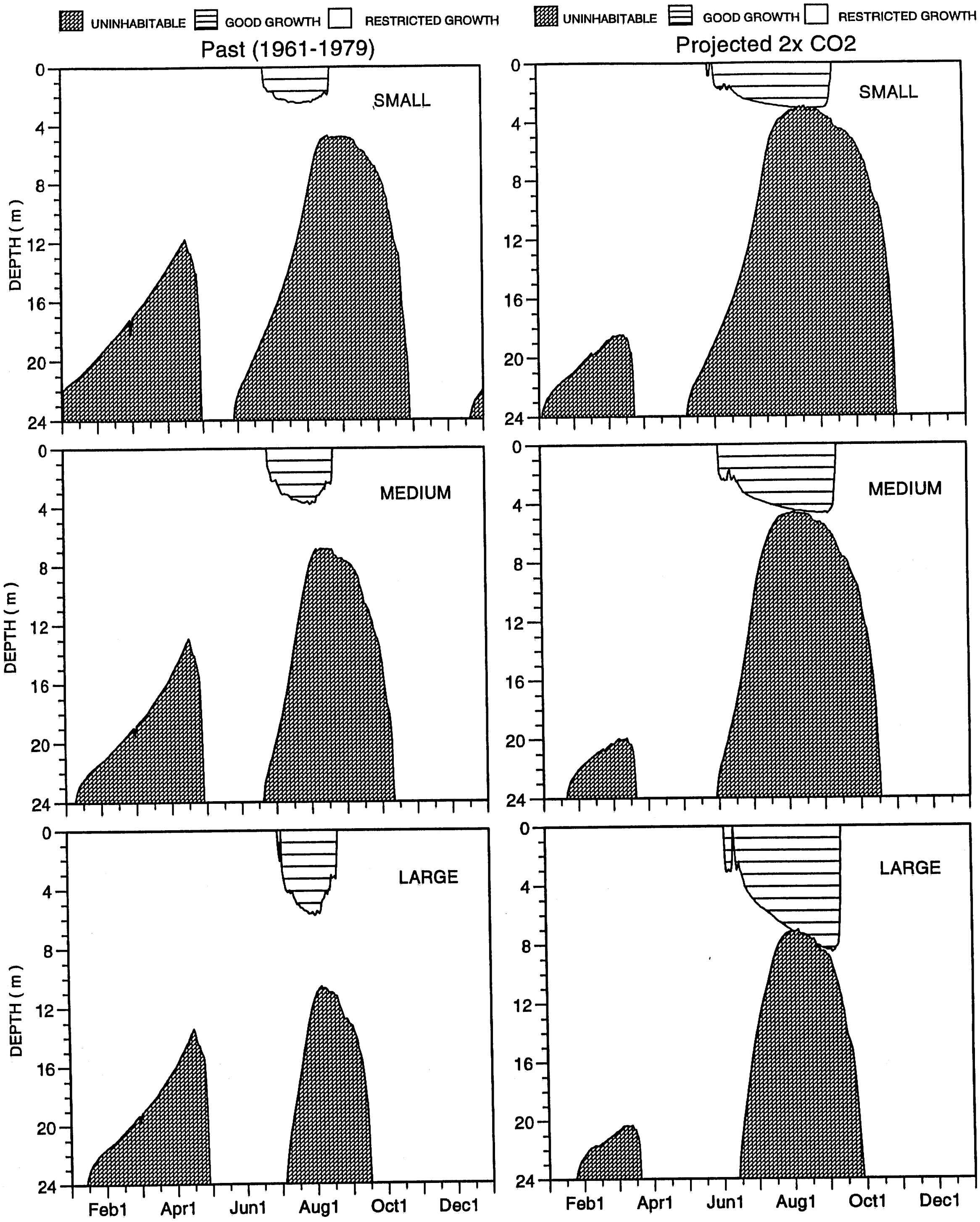

Figure 9c. Depth-time contours of **warm-water** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

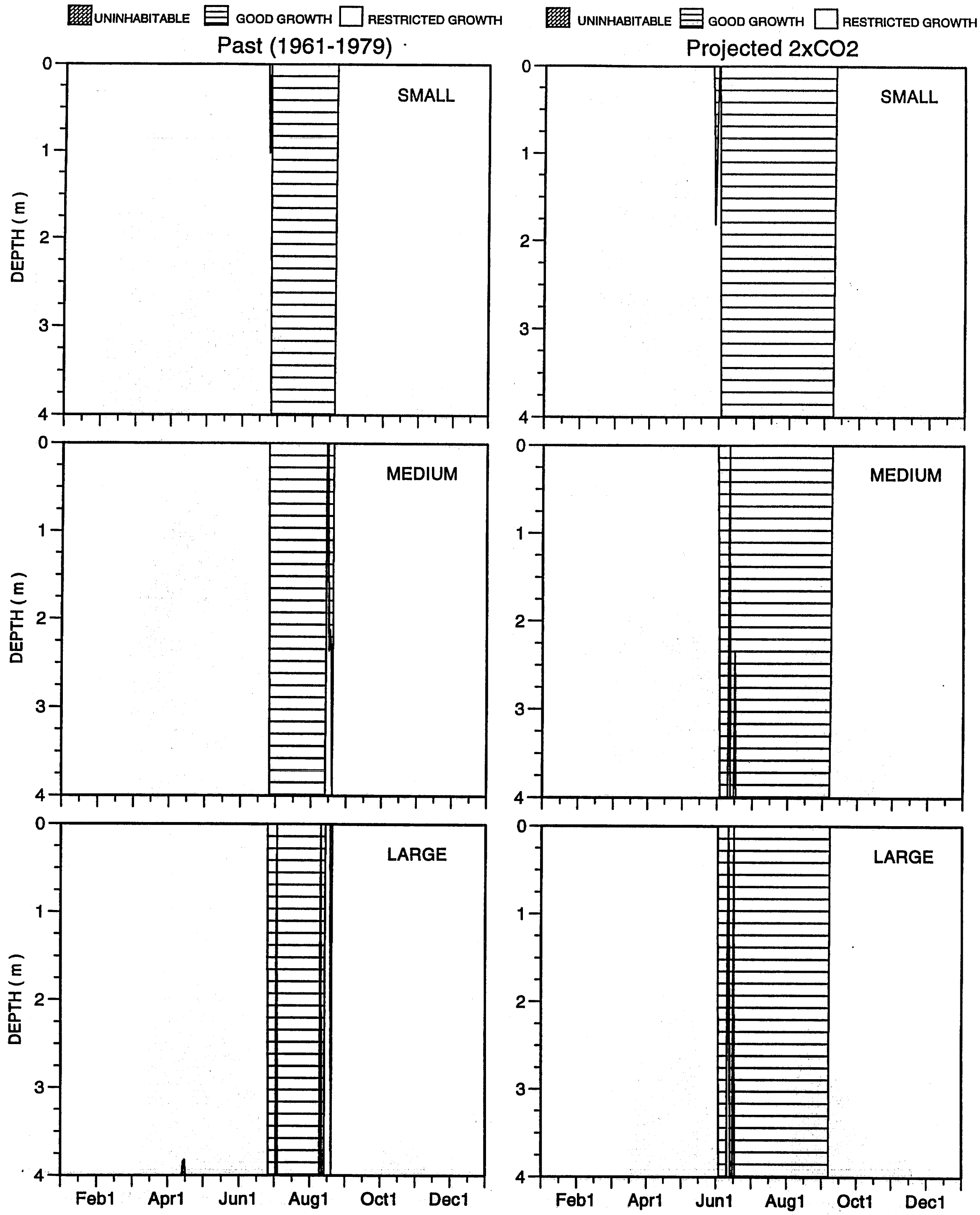

Figure 9d. Depth-time contours of **warm-water** fish habitats in **shallow** (4.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

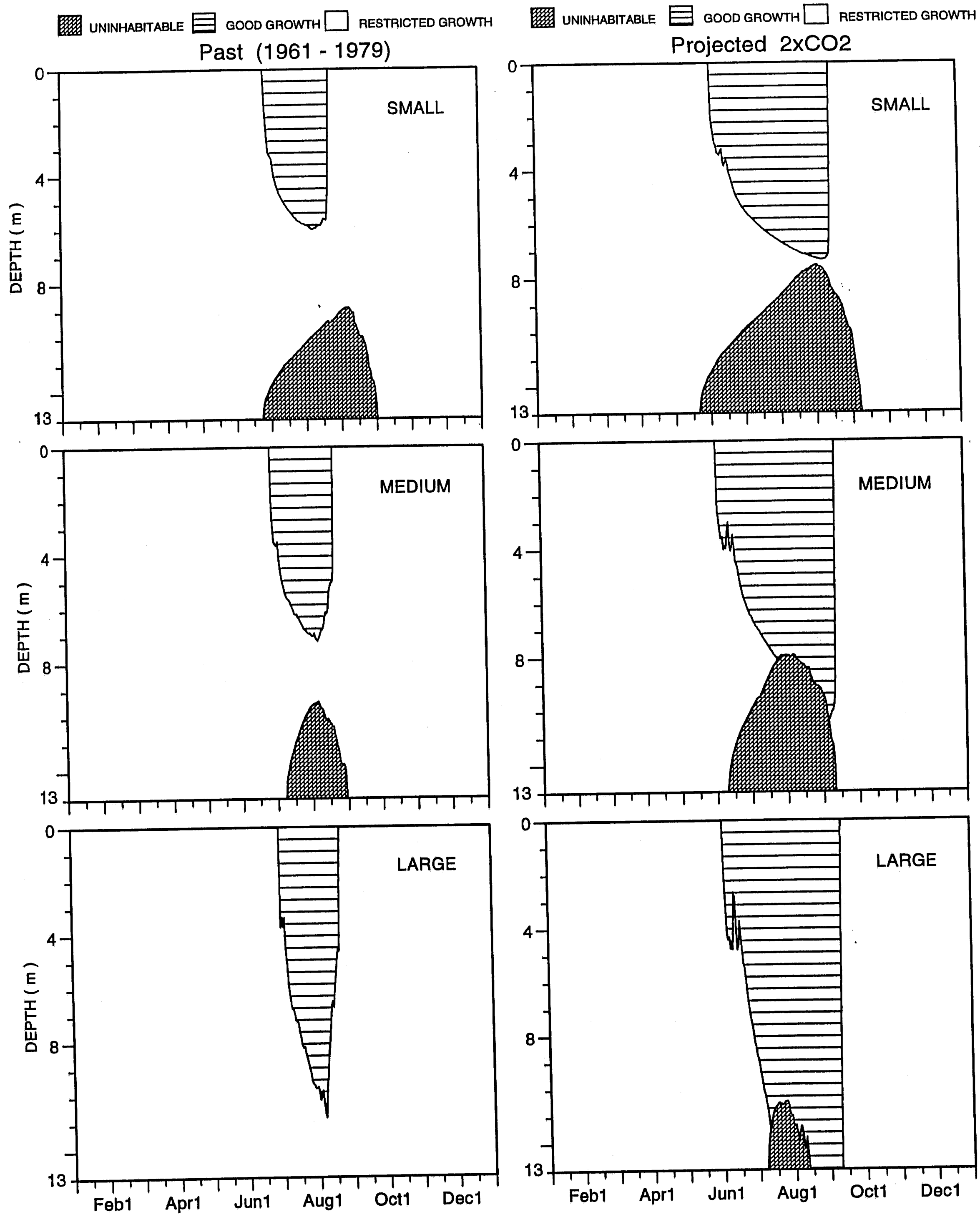

Figure 9e. Depth-time contours of **warm-water** fish habitats in **medium depth** (13.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

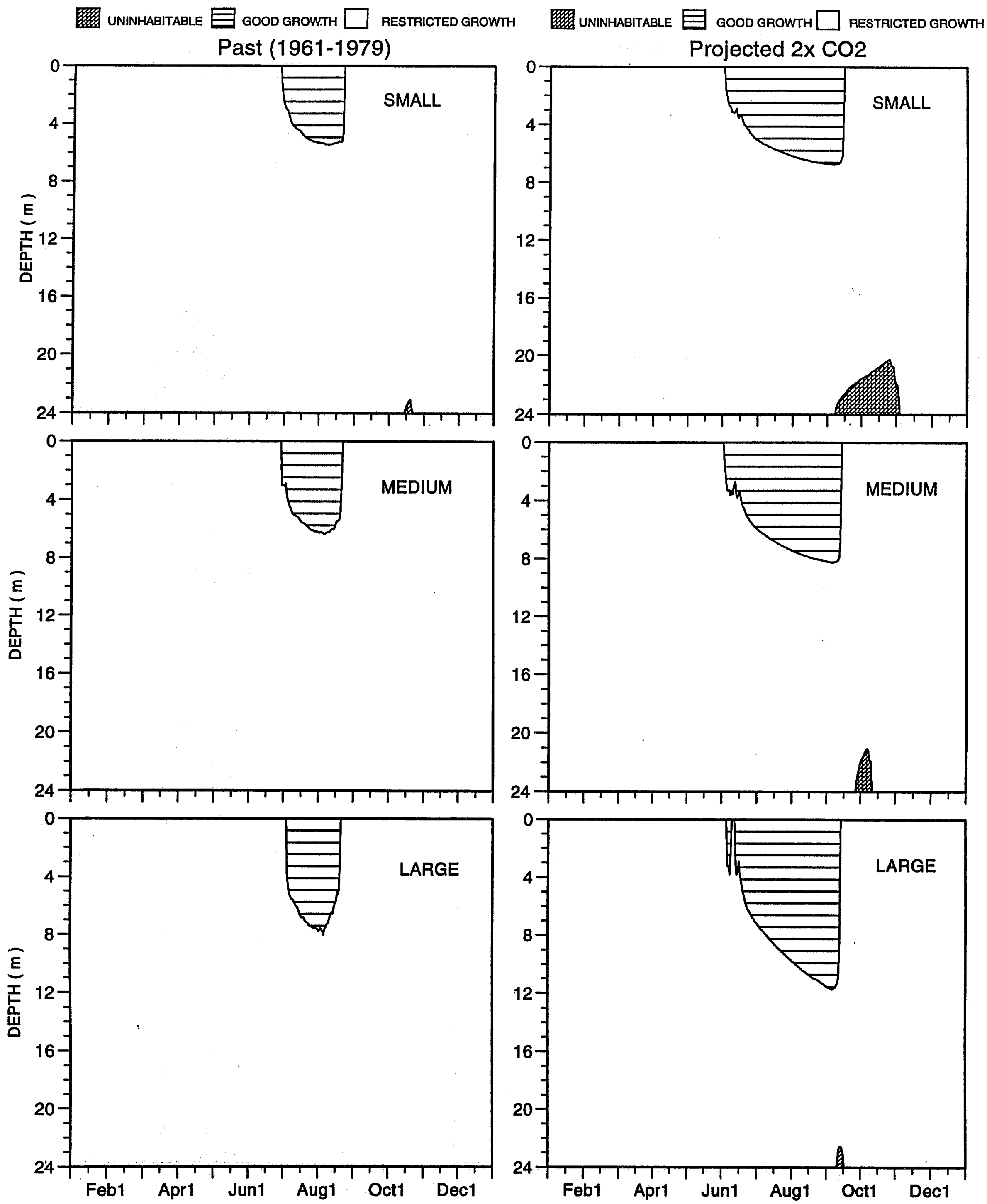

Figure 9f. Depth-time contours of **warm-water** fish habitats in **deep** (24.0 m) **oligotrophic** lakes at **Duluth, MN**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

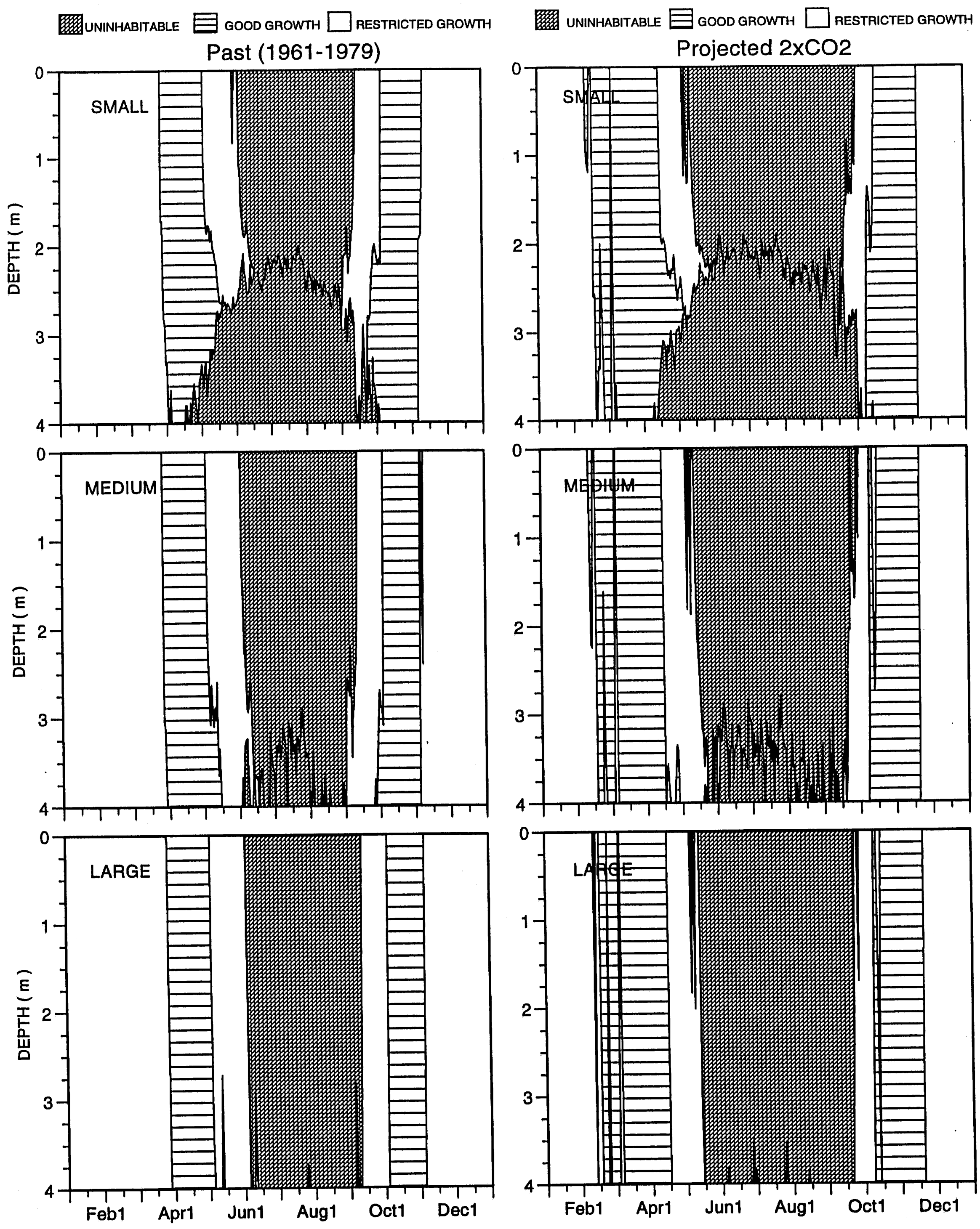

Figure 10a. Depth-time contours of **cold-water** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Kansas, MO,** under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

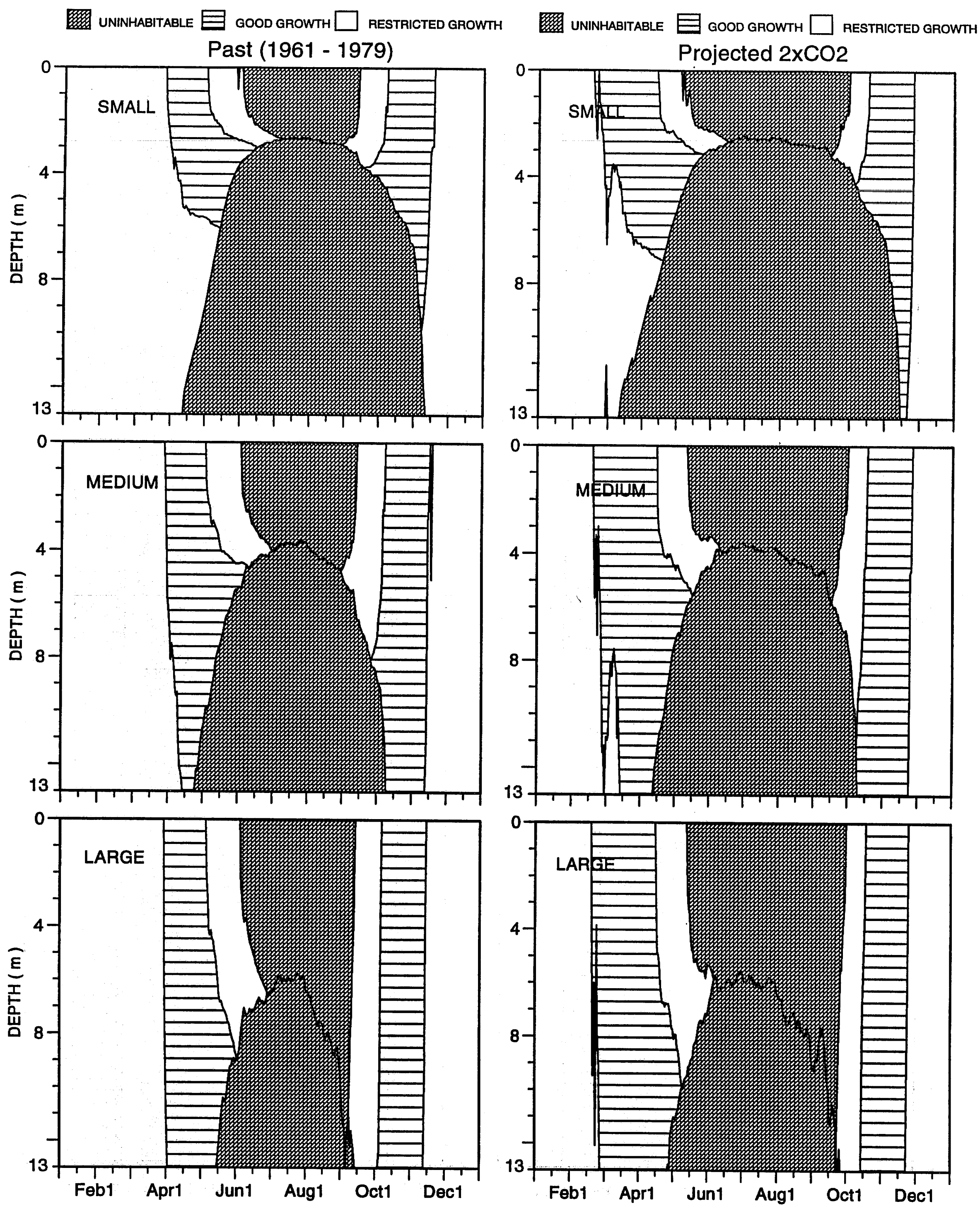

Figure 10b. Depth-time contours of **cold-water** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Kansas, MO,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

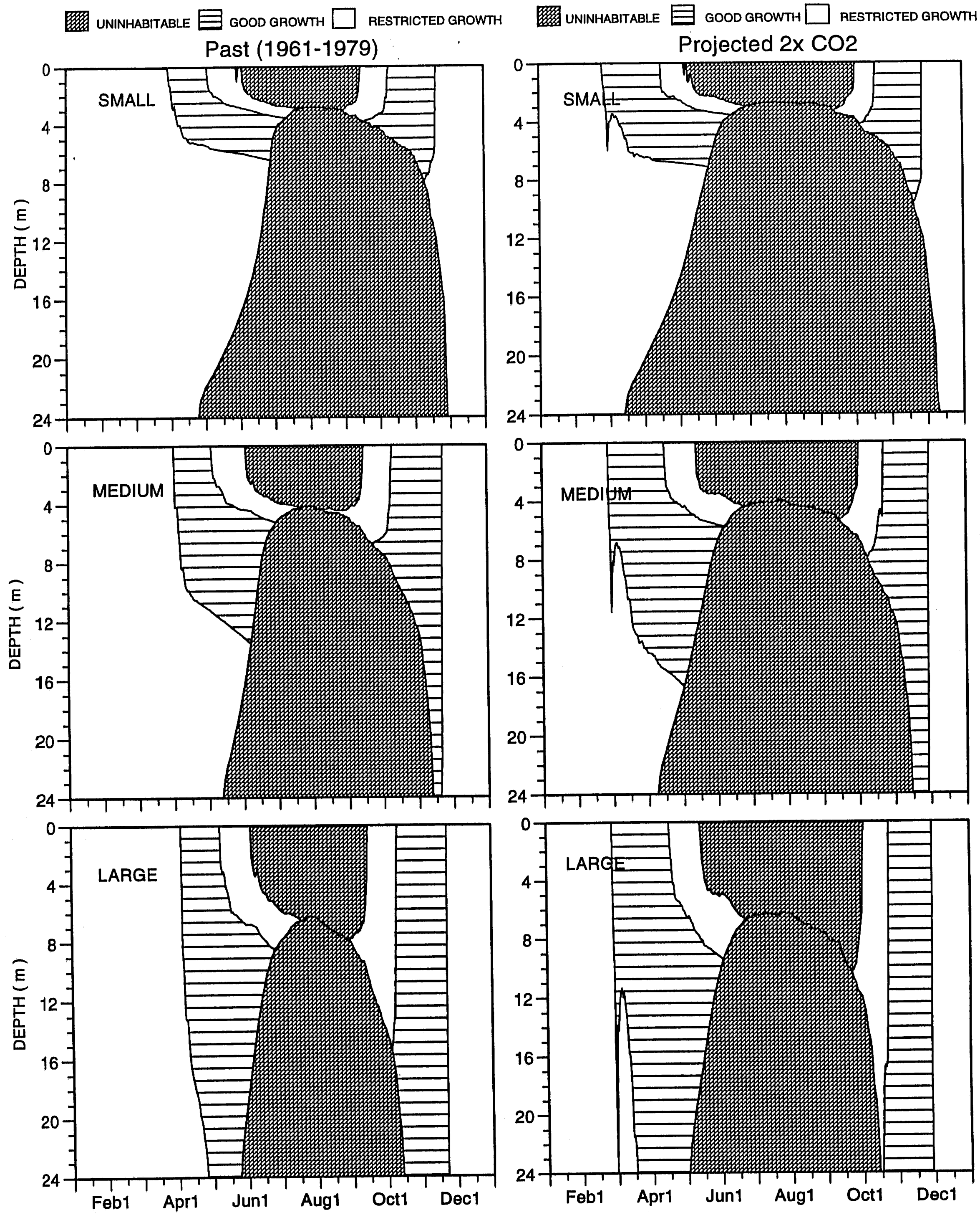

Figure 10c. Depth-time contours of **cold-water** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Kansas, MO,** under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

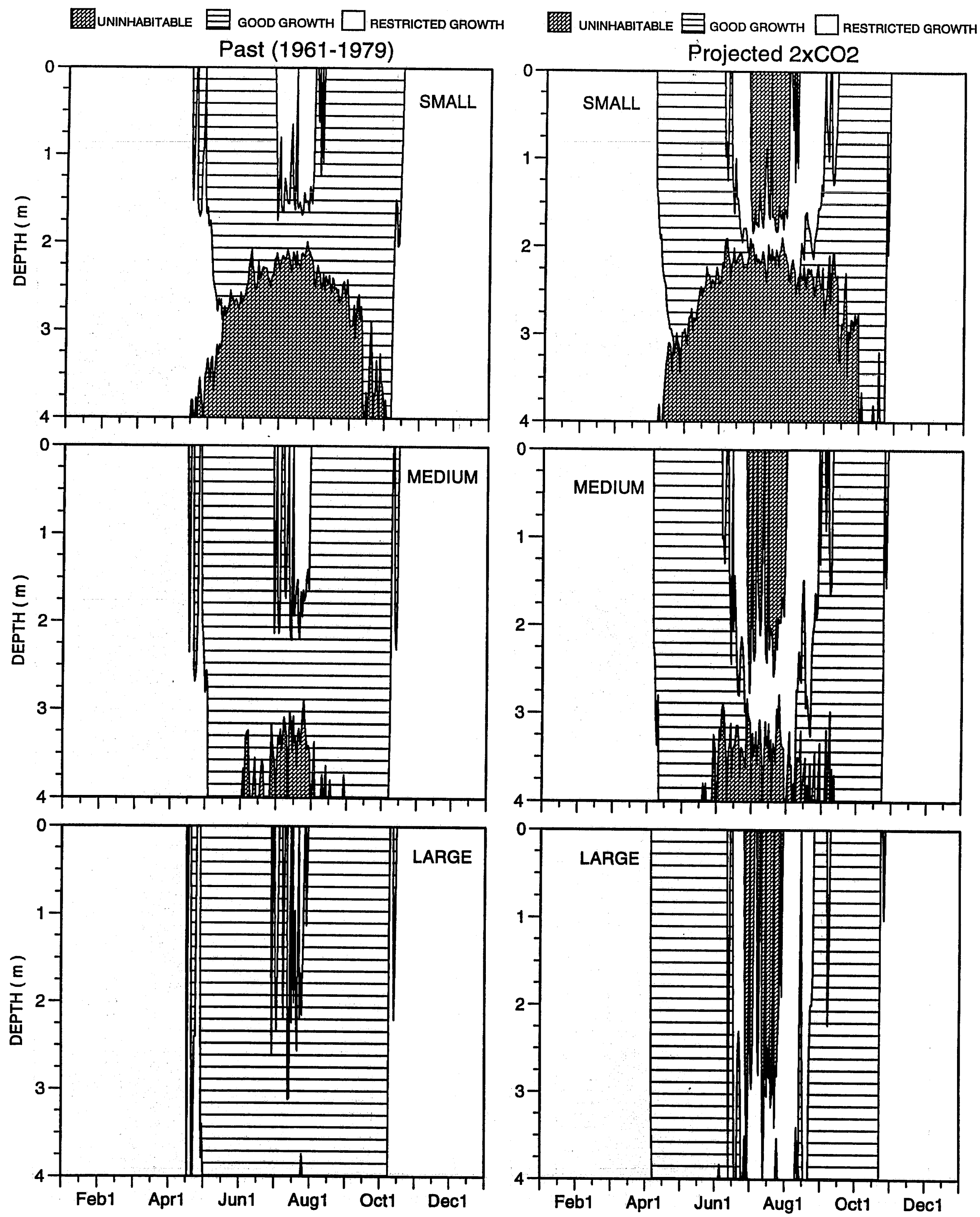

Figure 11a. Depth-time contours of **cool-water** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Kansas, MO**, under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

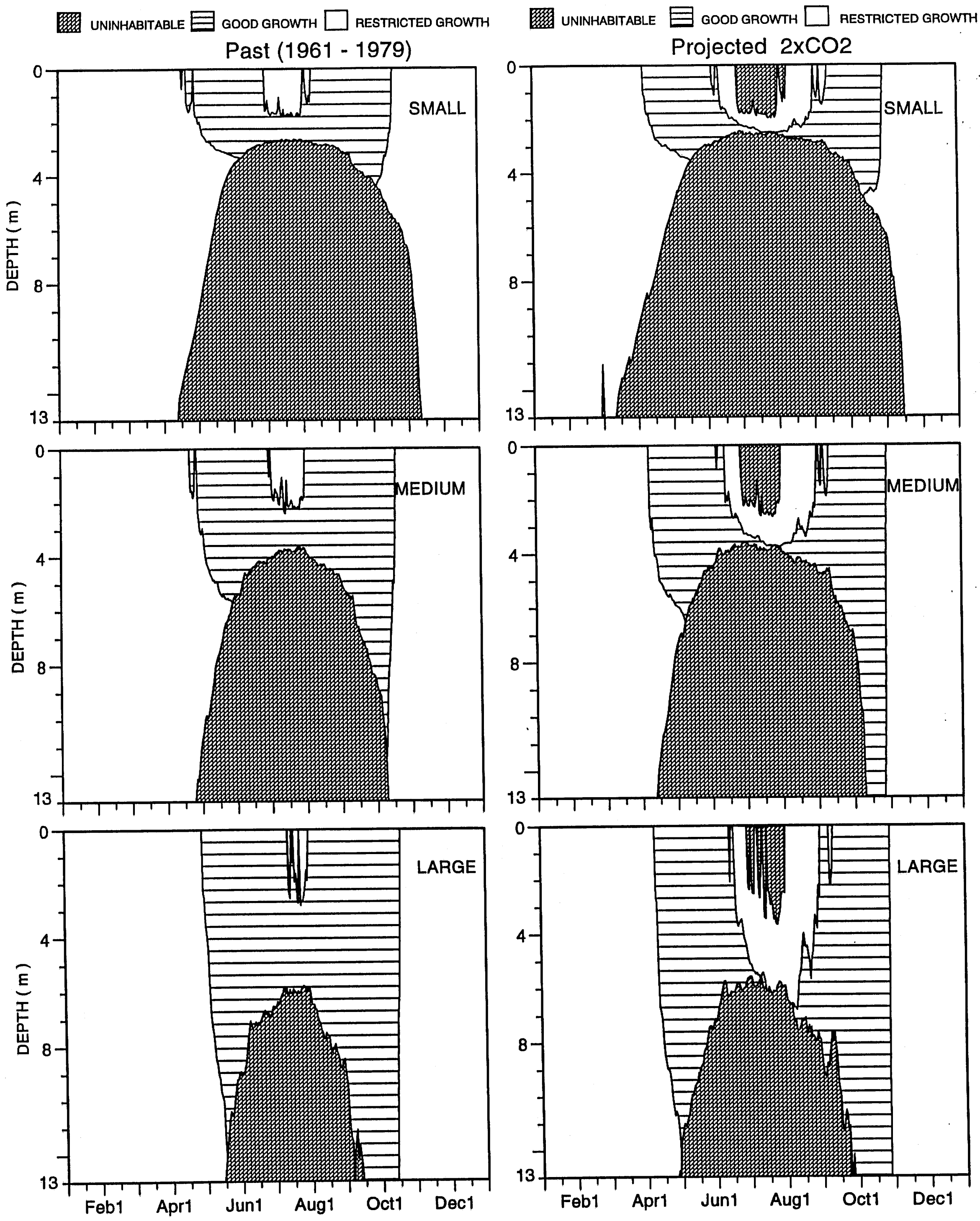

Figure 11b. Depth-time contours of **cool-water** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Kansas, MO,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

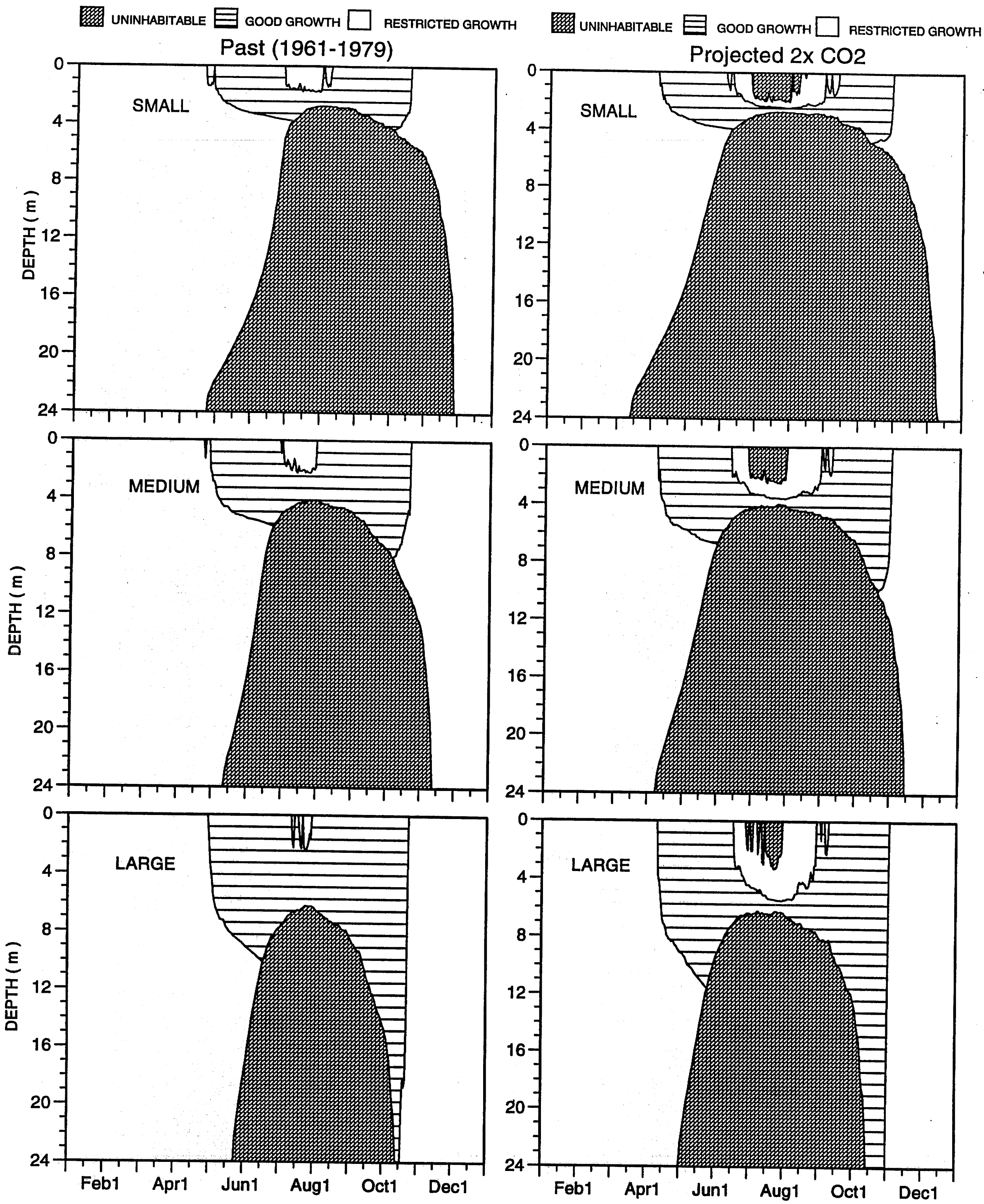

Figure 11c. Depth-time contours of **cool-water** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Kansas, MO,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

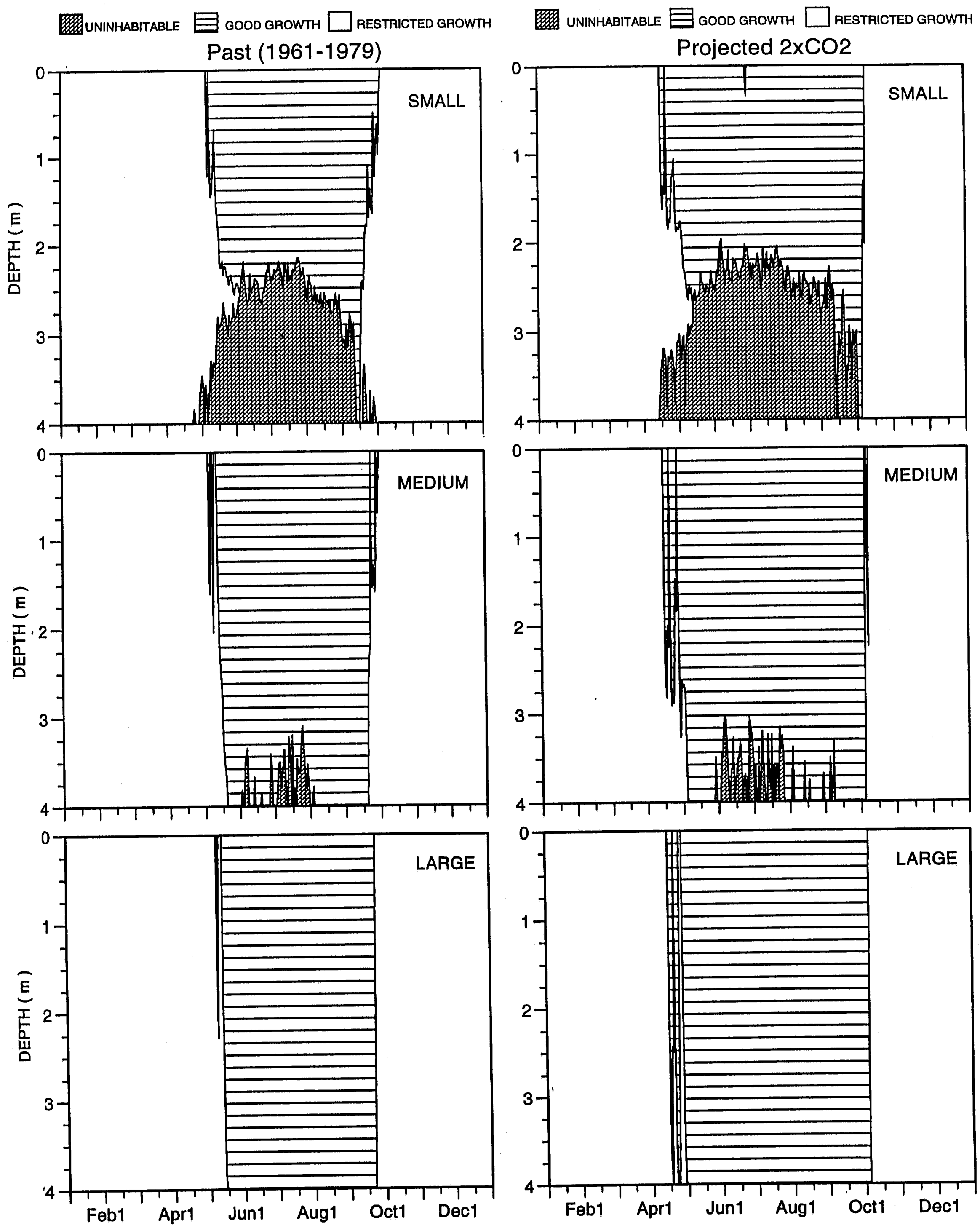

Figure 12a. Depth-time contours of **warmwater** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Kansas, MO,** under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

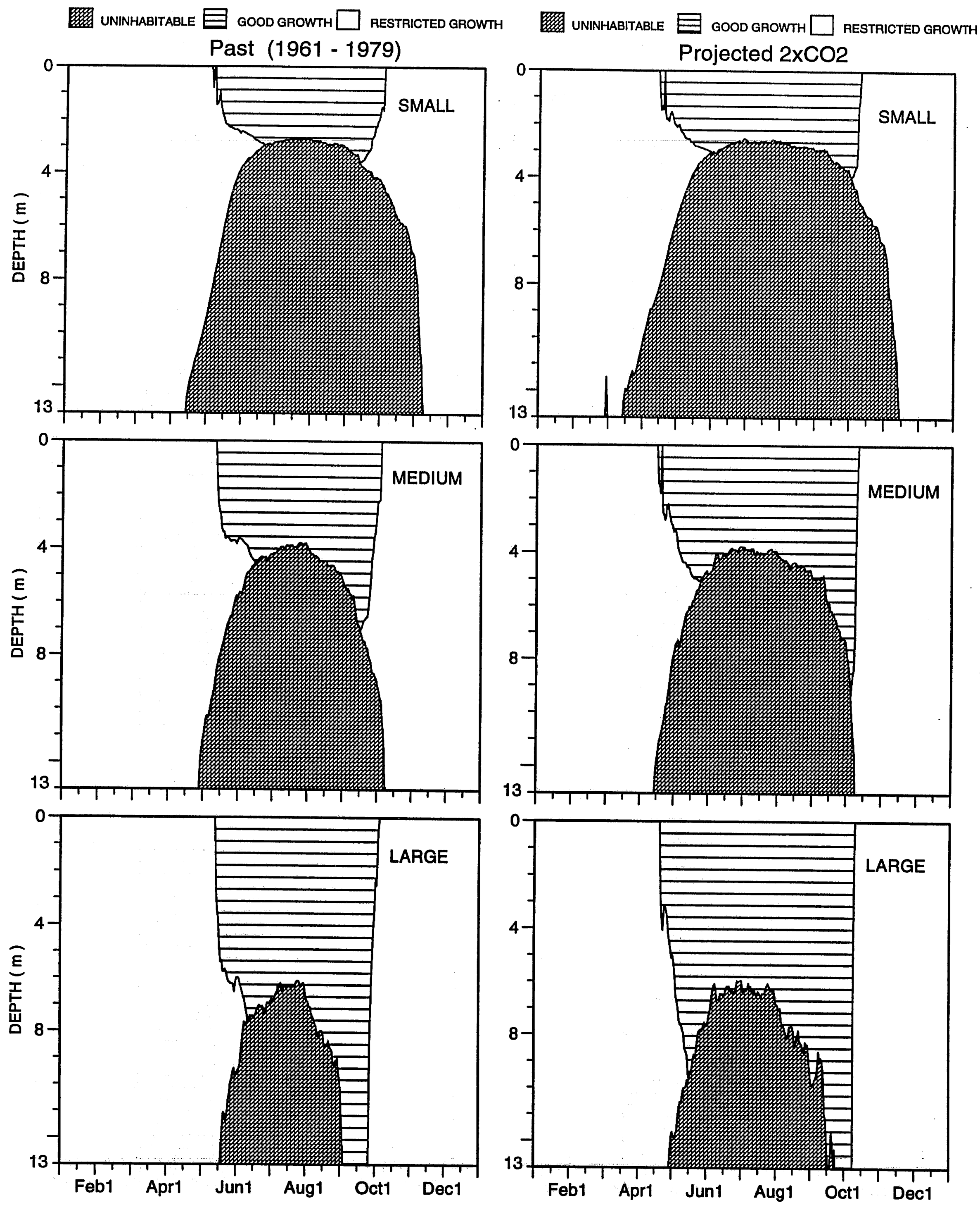

Figure 12b. Depth-time contours of **warmwater** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Kansas, MO,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

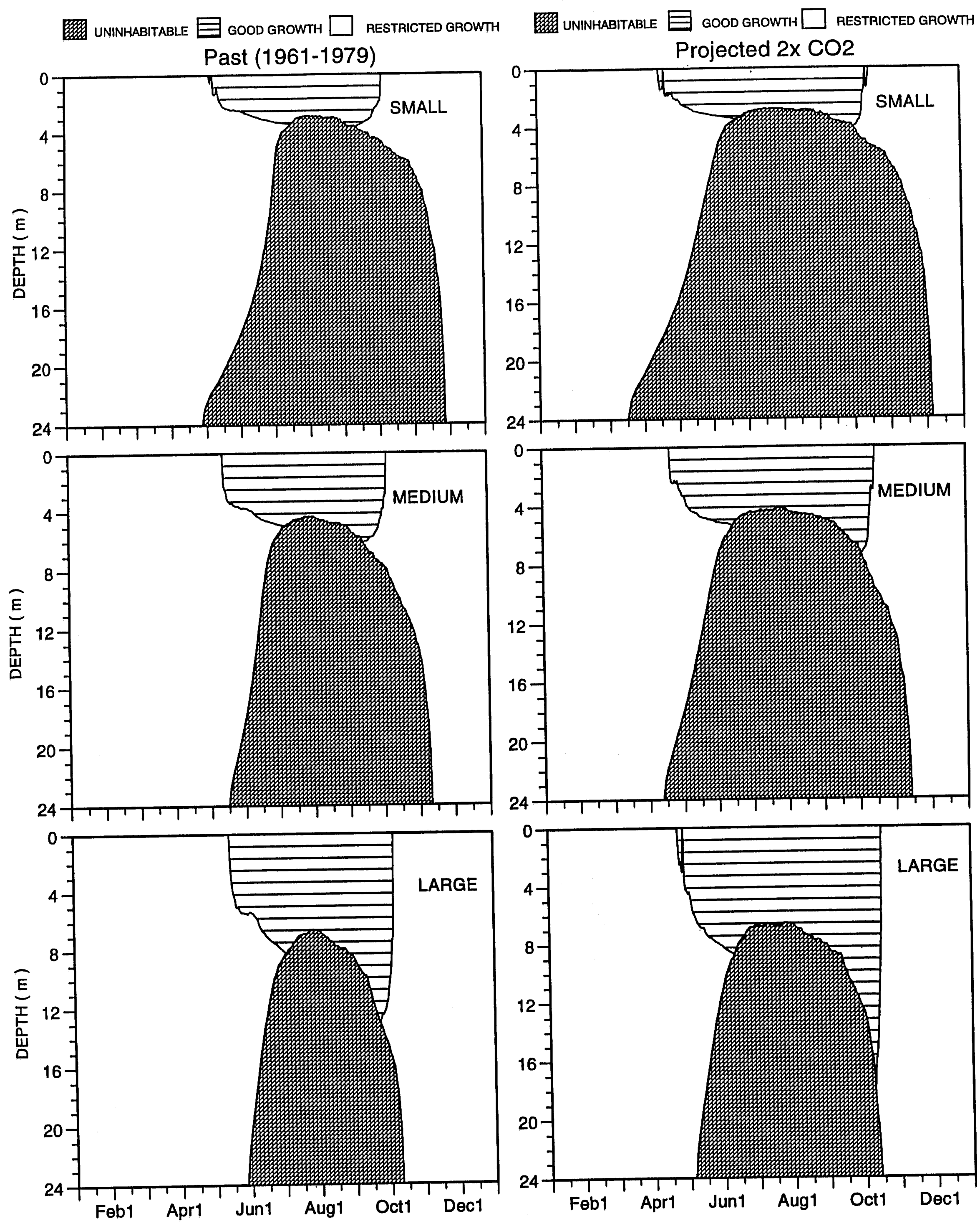

Figure 12c. Depth-time contours of **warmwater** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Kansas, MO,** under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

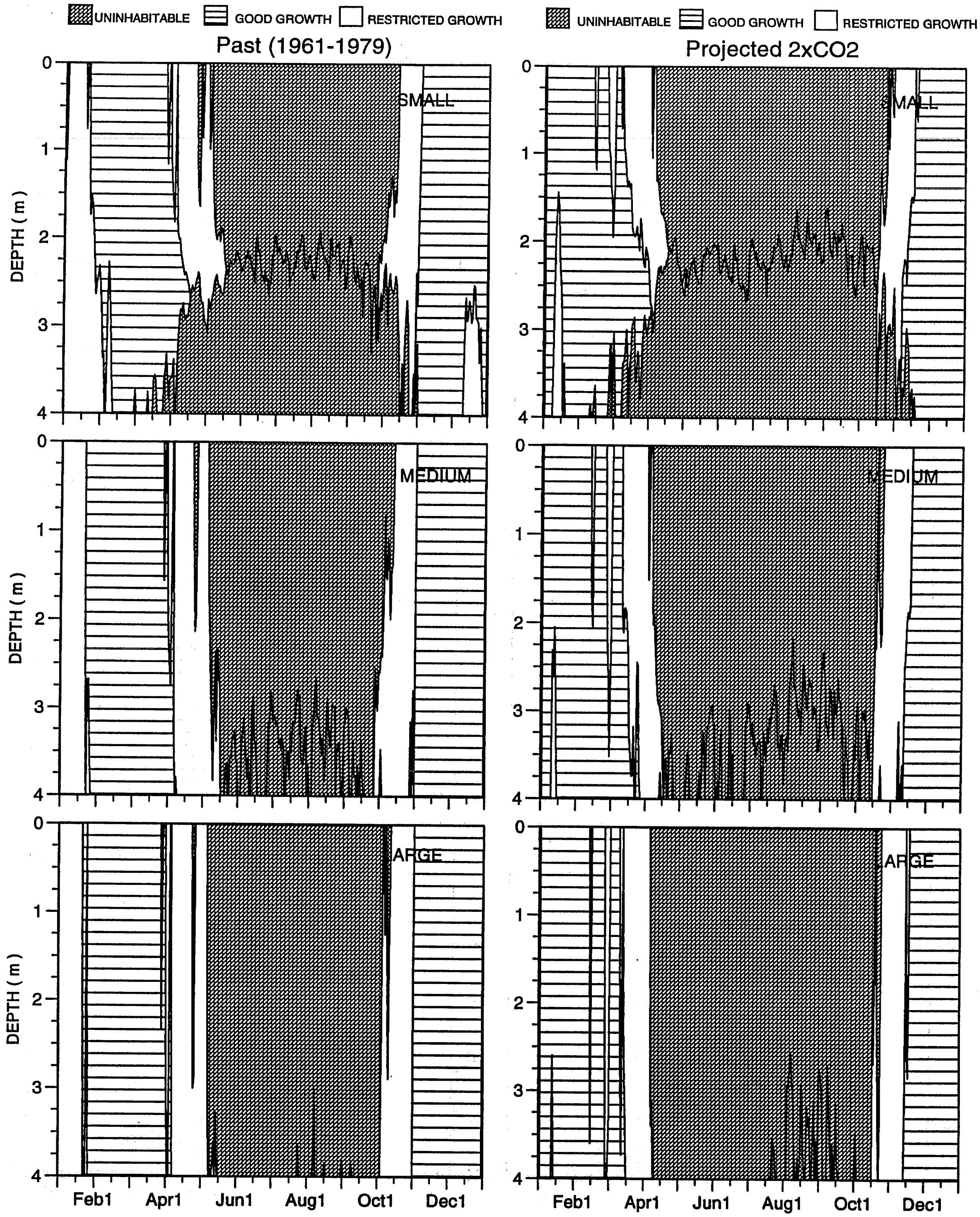

Figure 13a. Depth-time contours of **cold-water** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Austin, TX,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

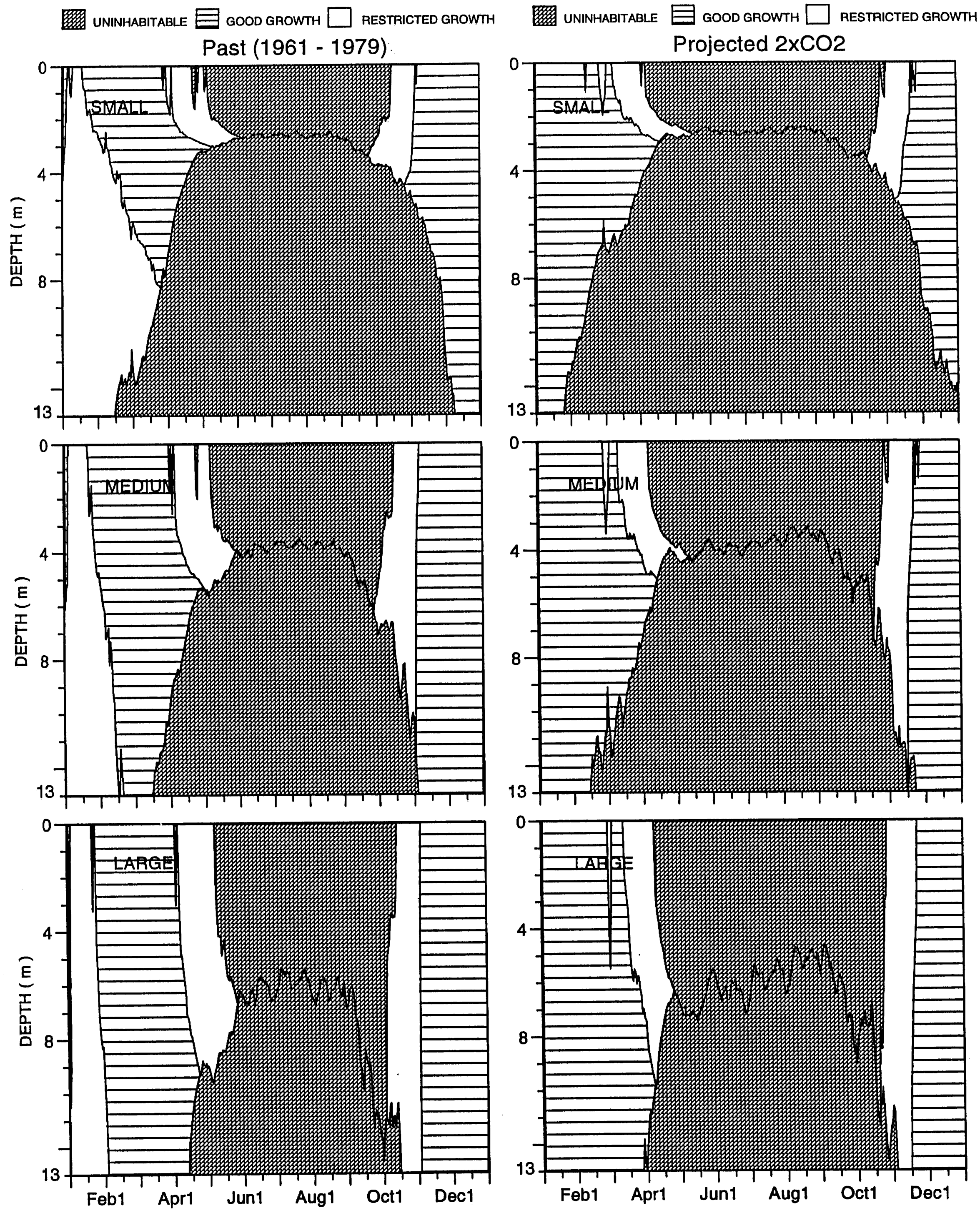

Figure 13b. Depth-time contours of **cold-water** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Austin, TX,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

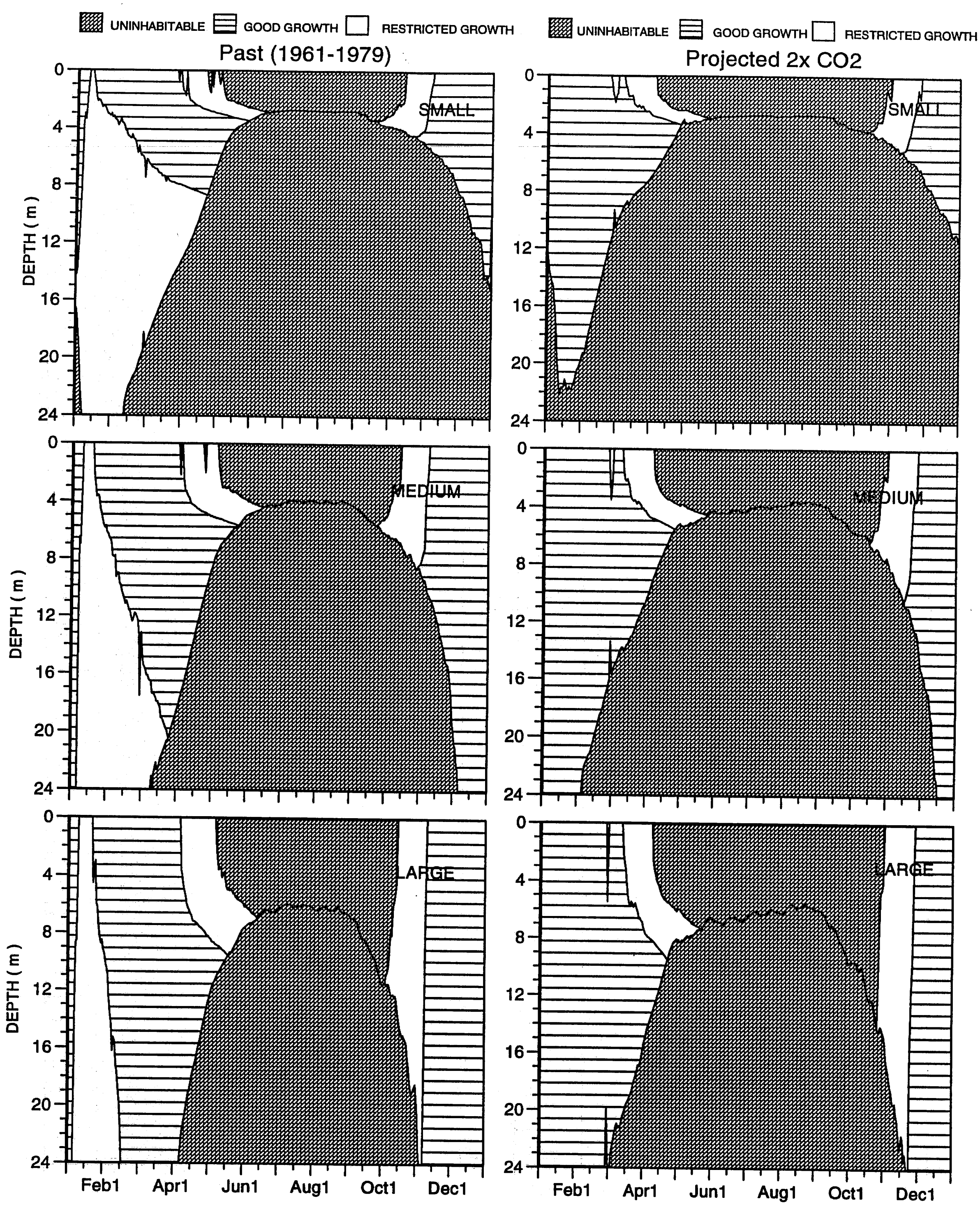

Figure 13c. Depth-time contours of **cold-water** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Austin, TX,** under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

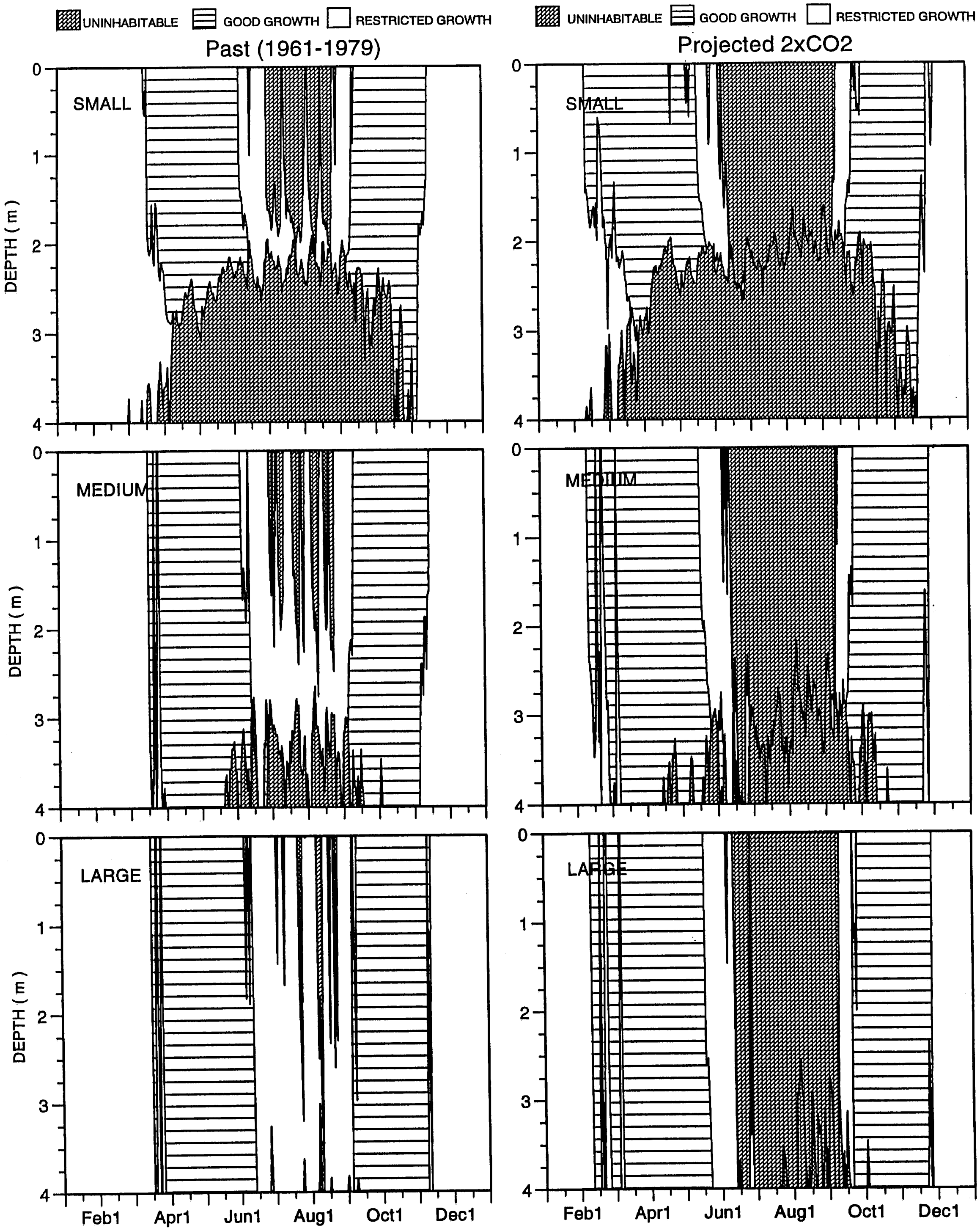

Figure 14a. Depth-time contours of **cool-water** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Austin, TX**, under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

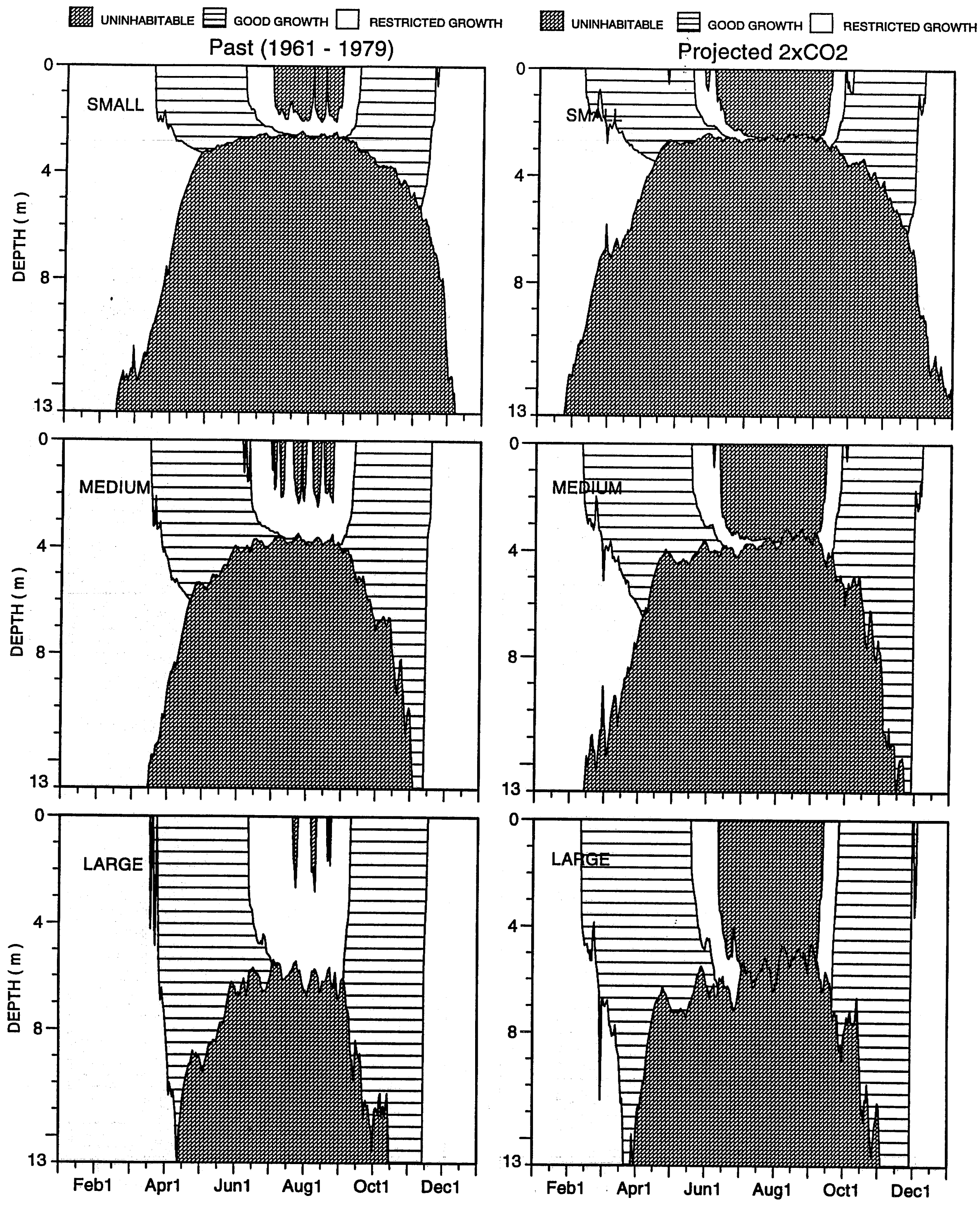

Figure 14b. Depth-time contours of **cool-water** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Austin, TX,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small ($0.2\ km^2$), medium ($1.7\ km^2$) and large ($10.0\ km^2$) surface areas are shown.

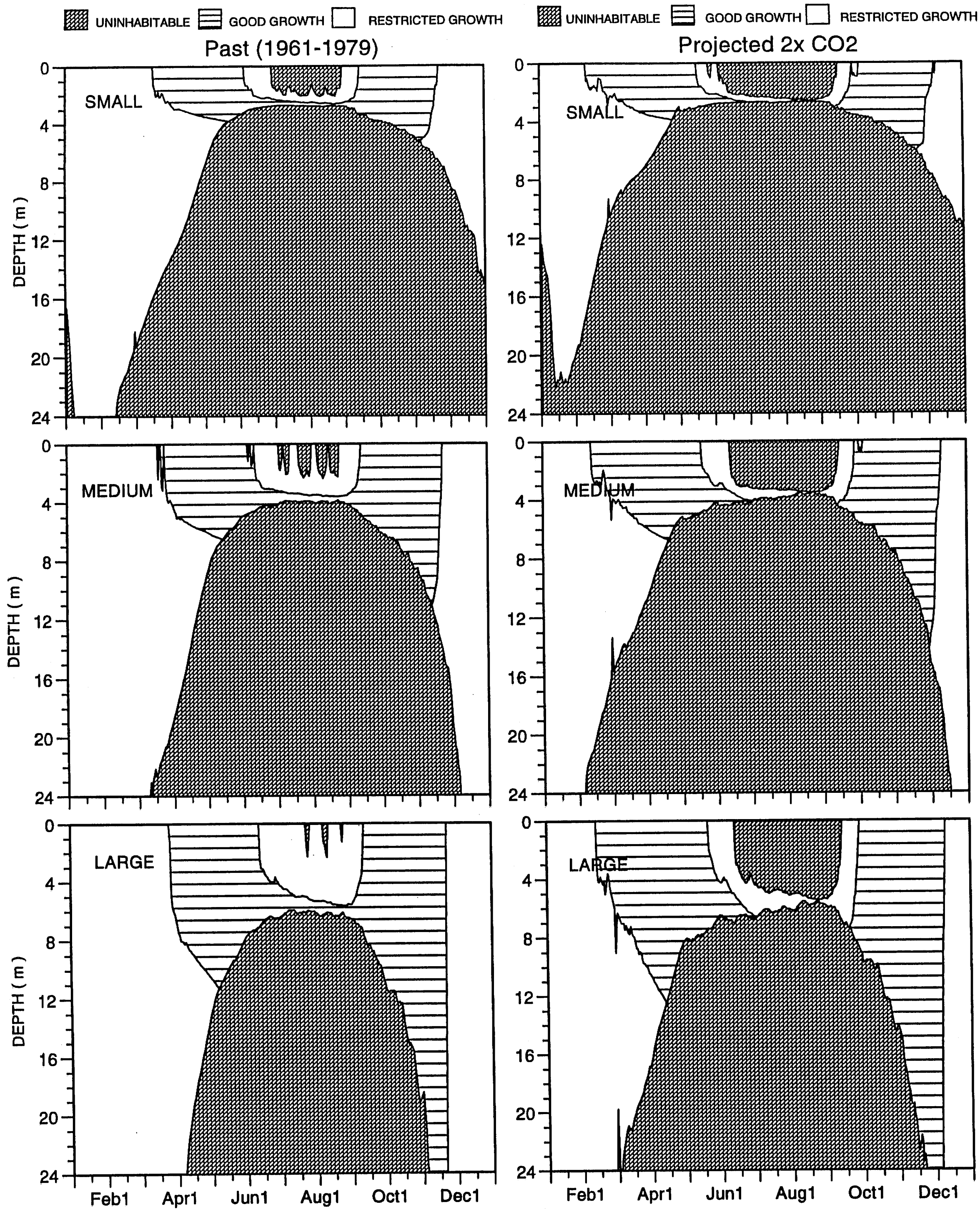

Figure 14c. Depth-time contours of **cool-water** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Austin, TX,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

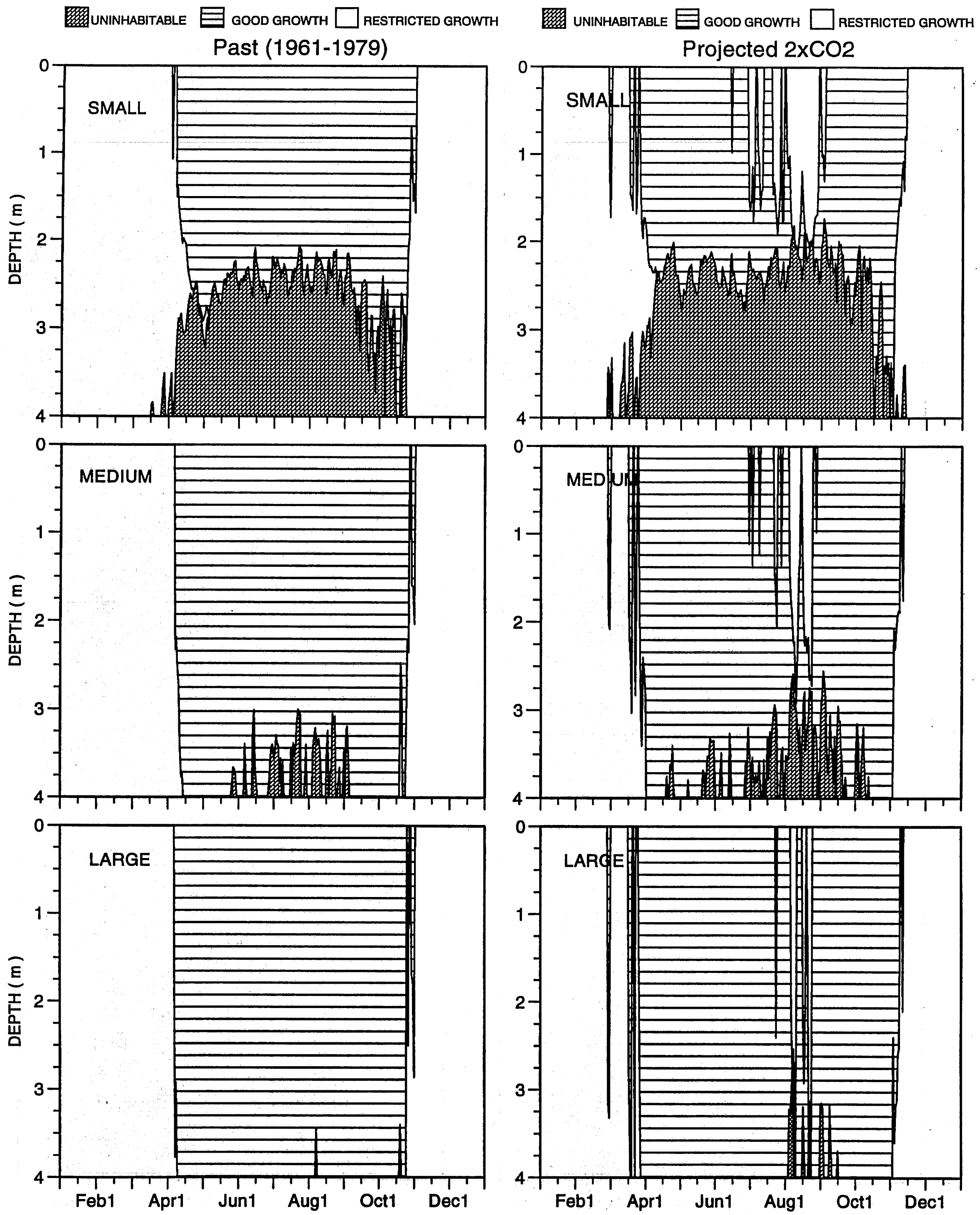

Figure 15a. Depth-time contours of **warmwater** fish habitats in **shallow** (4.0 m) **eutrophic** lakes at **Austin, TX,** under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

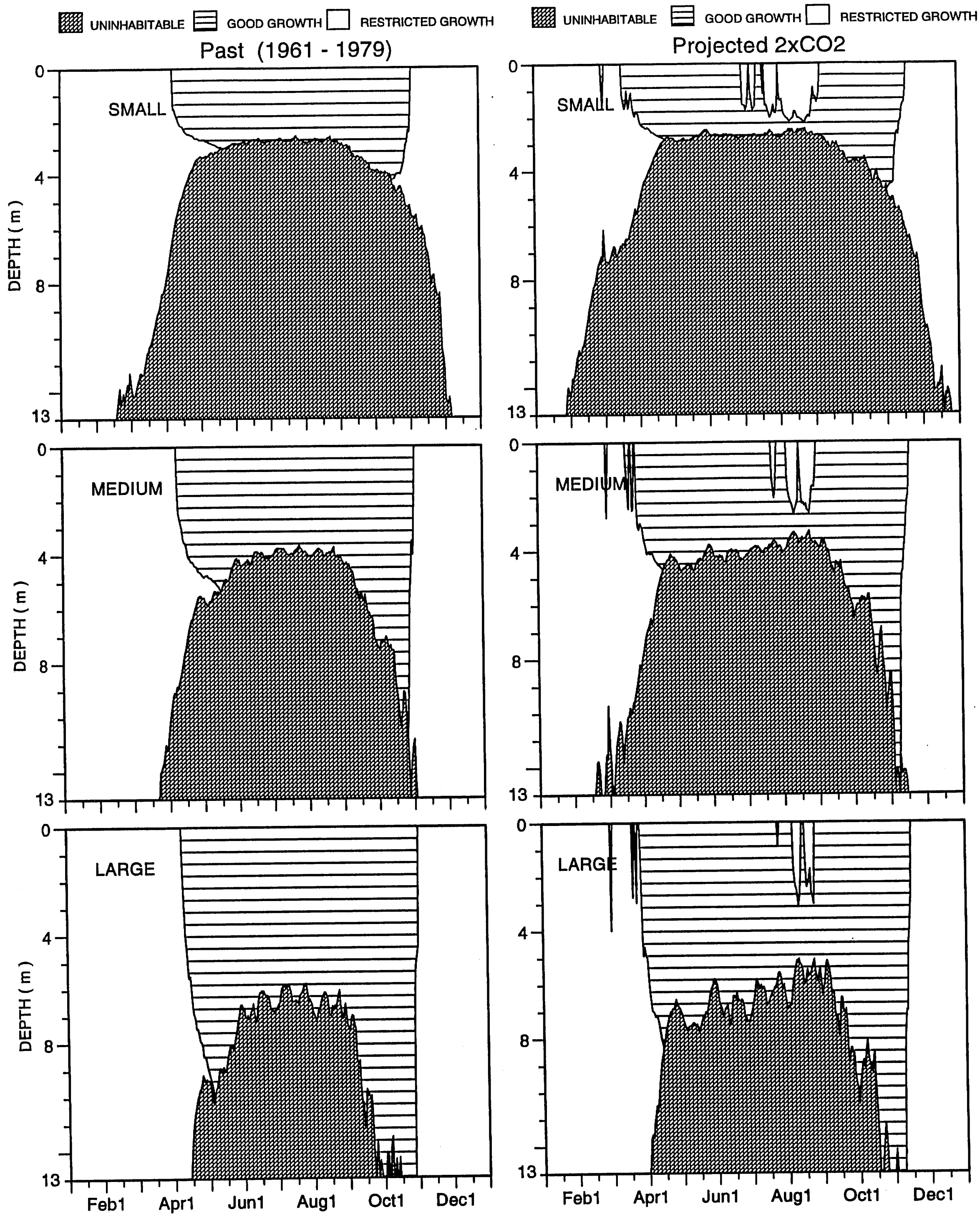

Figure 15b. Depth-time contours of **warmwater** fish habitats in **medium depth** (13.0 m) **eutrophic** lakes at **Austin, TX,** under past (1961-1979) climate conditions (left) and projected 2xCO_2 CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

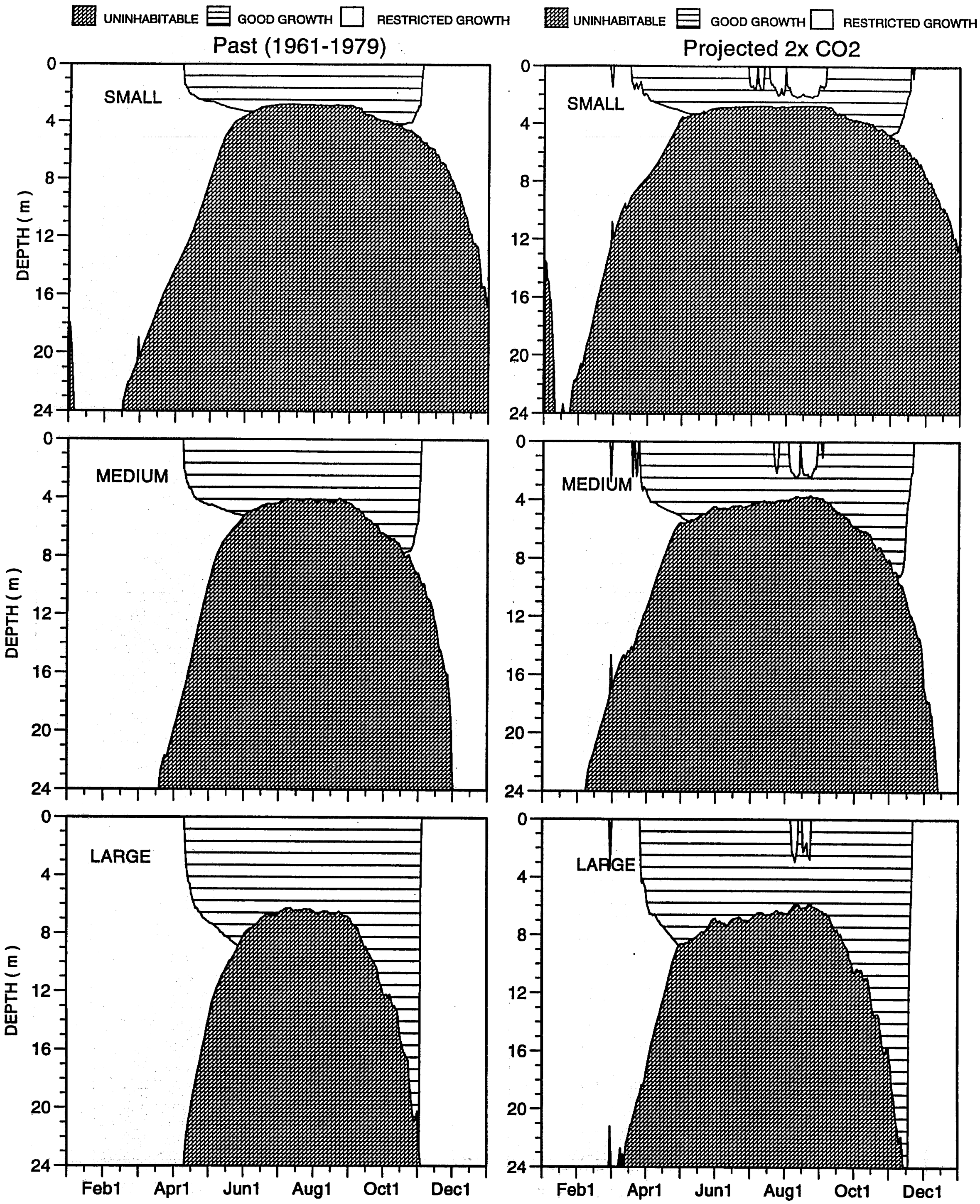

Figure 15c. Depth-time contours of **warmwater** fish habitats in **deep** (24.0 m) **eutrophic** lakes at **Austin, TX,** under past (1961-1979) climate conditions (left) and projected $2xCO_2$ CCC climate scenario (right). Lakes with small (0.2 km^2), medium (1.7 km^2) and large (10.0 km^2) surface areas are shown.

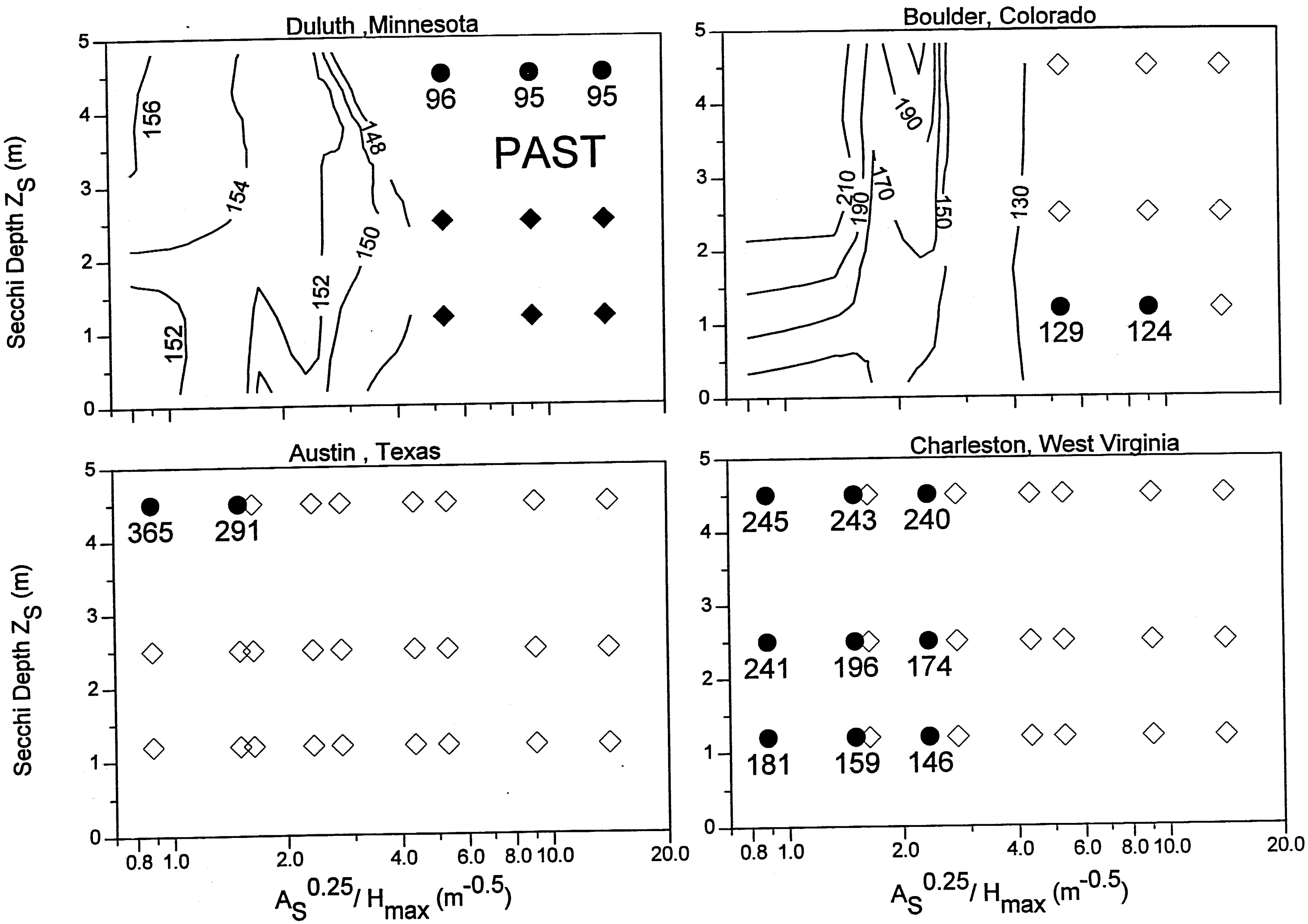

Fig. 16a Simulated **good-growth length (days)** for **cold-water fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled and open diamonds* are lakes with uninhabitable space during *the winter and the summer, respectively.*

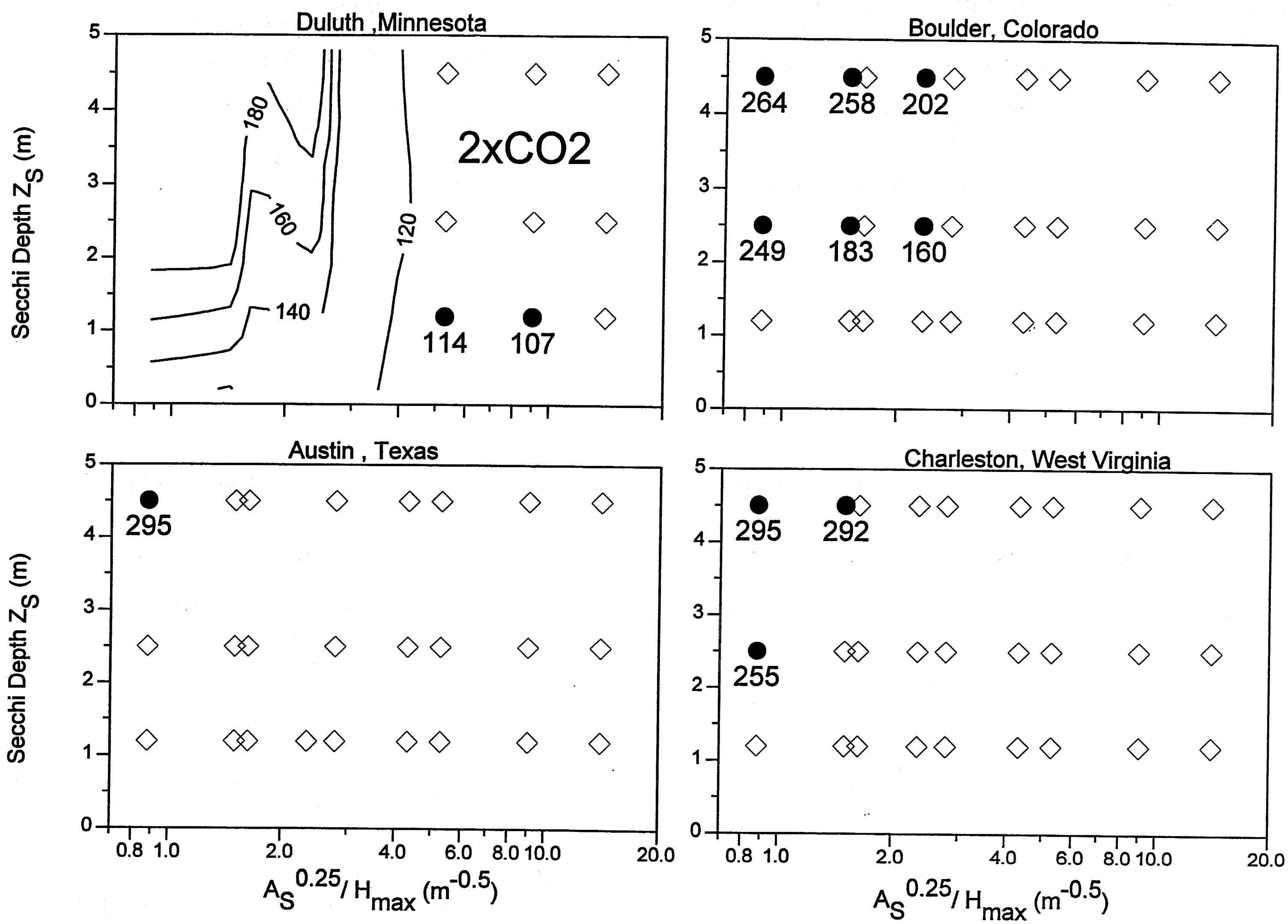

Fig. 16b Simulated **good-growth length (days)** for **cold-water fish** under **projected $2xCO_2$ climate scenario** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Open diamonds* are lakes with uninhabitable space during *the summer*.

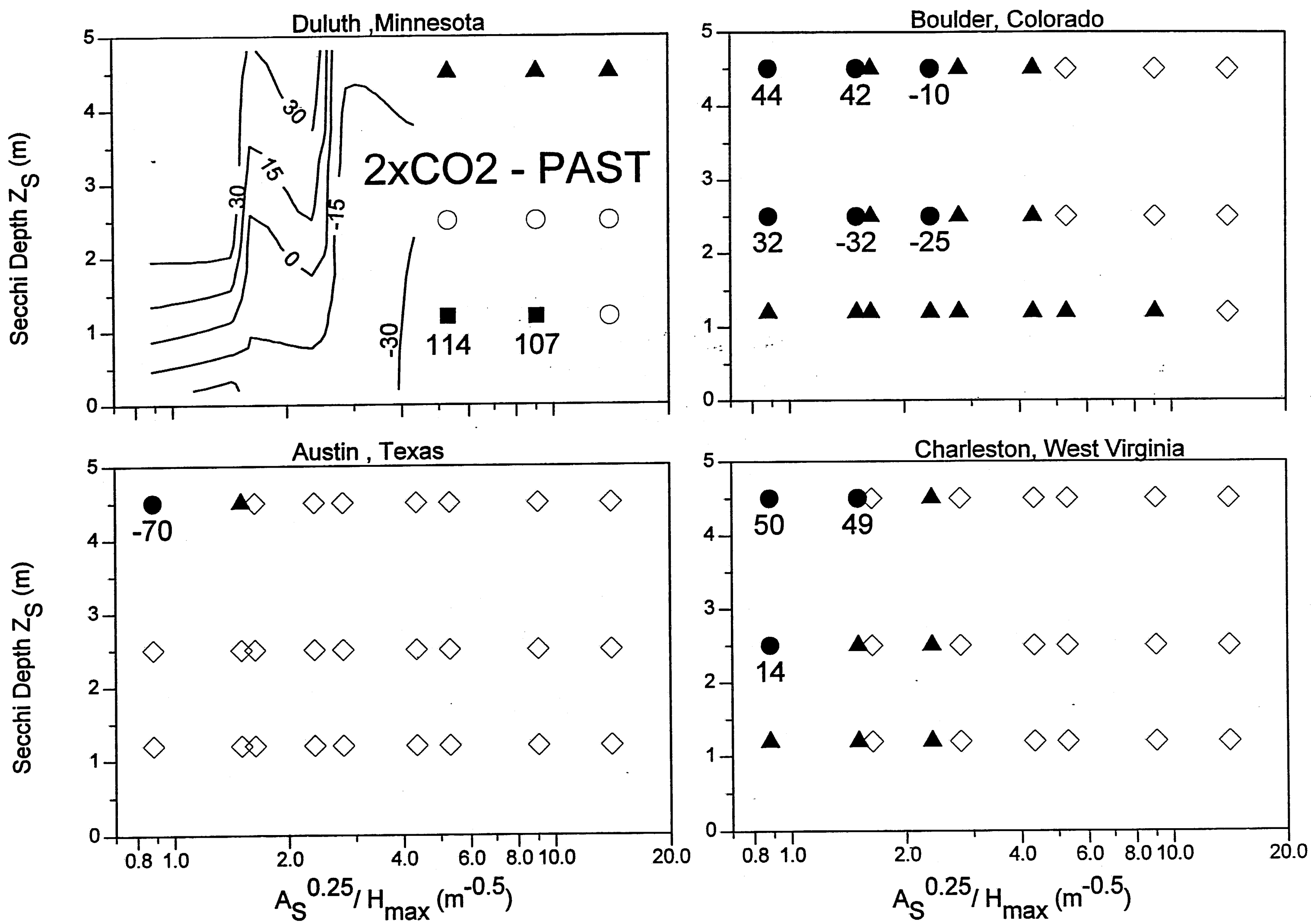

Fig. 16c **Differences** between projected and past climate conditions for simulated **good-growth length (days)** for **cold-water fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

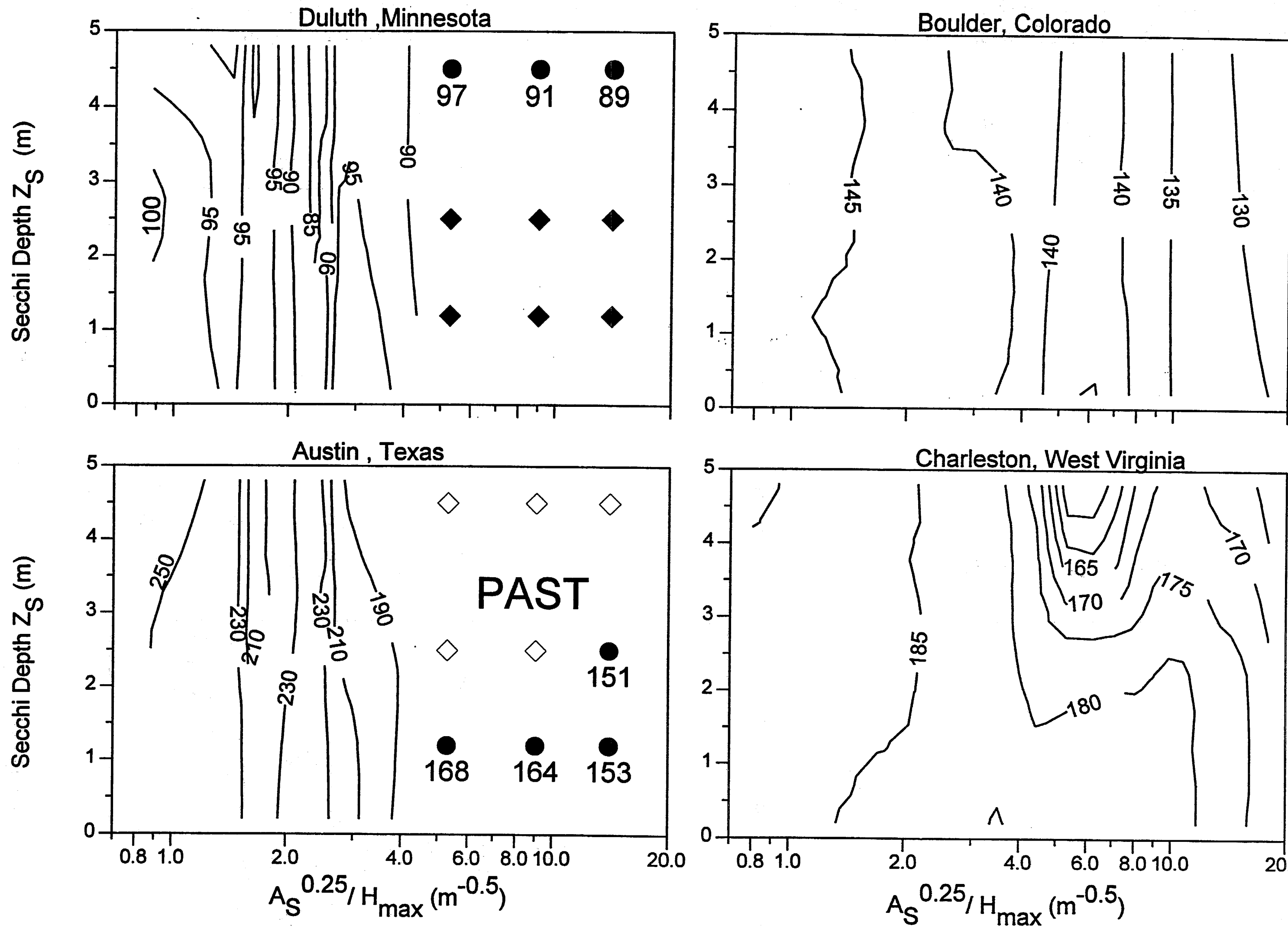

Fig. 17a Simulated **good-growth length (days)** for **cool-water fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled and open diamonds* are lakes with uninhabitable space during *the winter and the summer, respectively.*

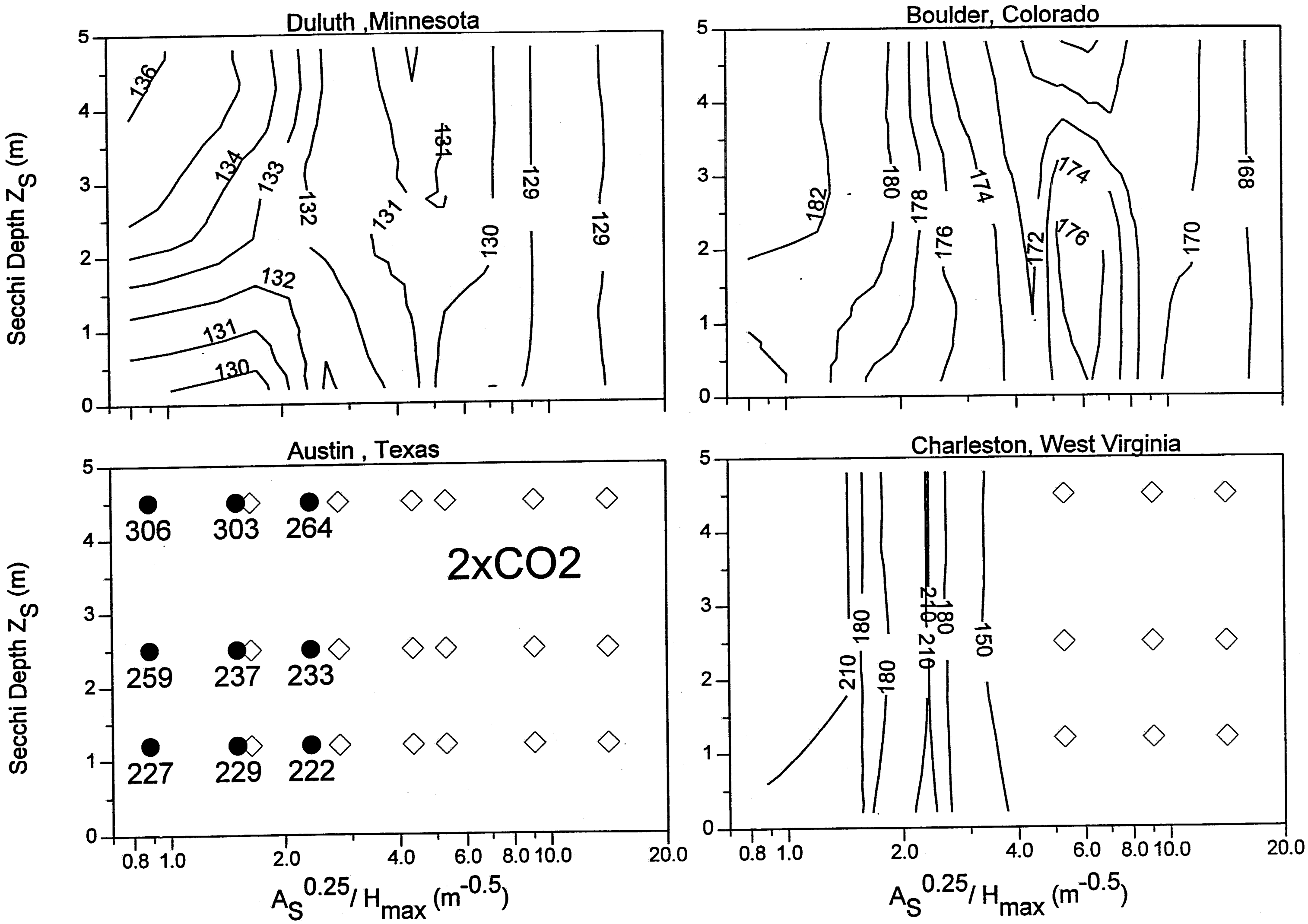

Fig. 17b Simulated **good-growth length (days)** for **cool-water fish** under **projected 2xCO_2 climate scenario** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Open diamonds* are lakes with uninhabitable space during *the summer*.

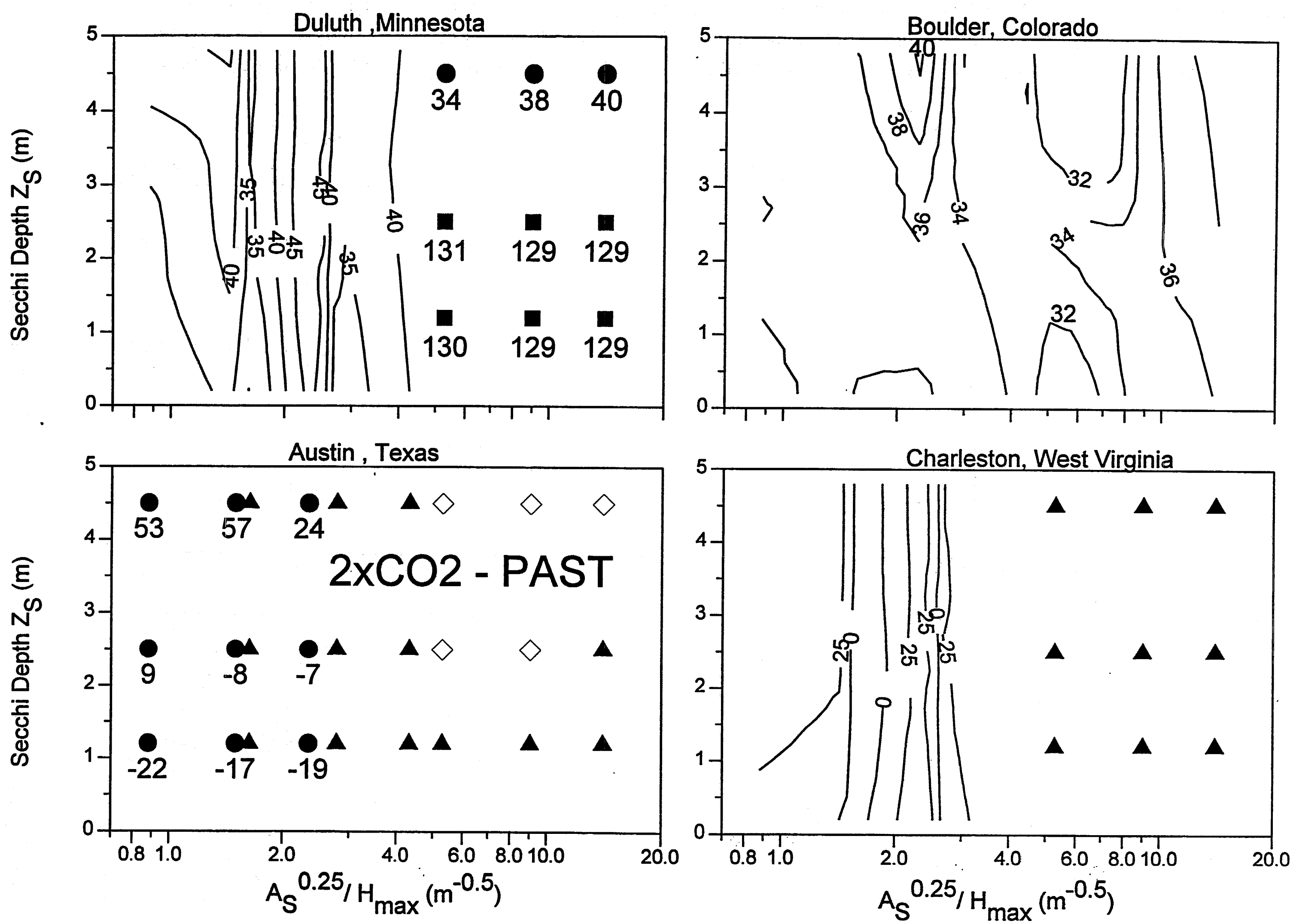

Fig. 17c **Differences** between projected and past climate conditions for simulated **good-growth length (days)** for **cool-water fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

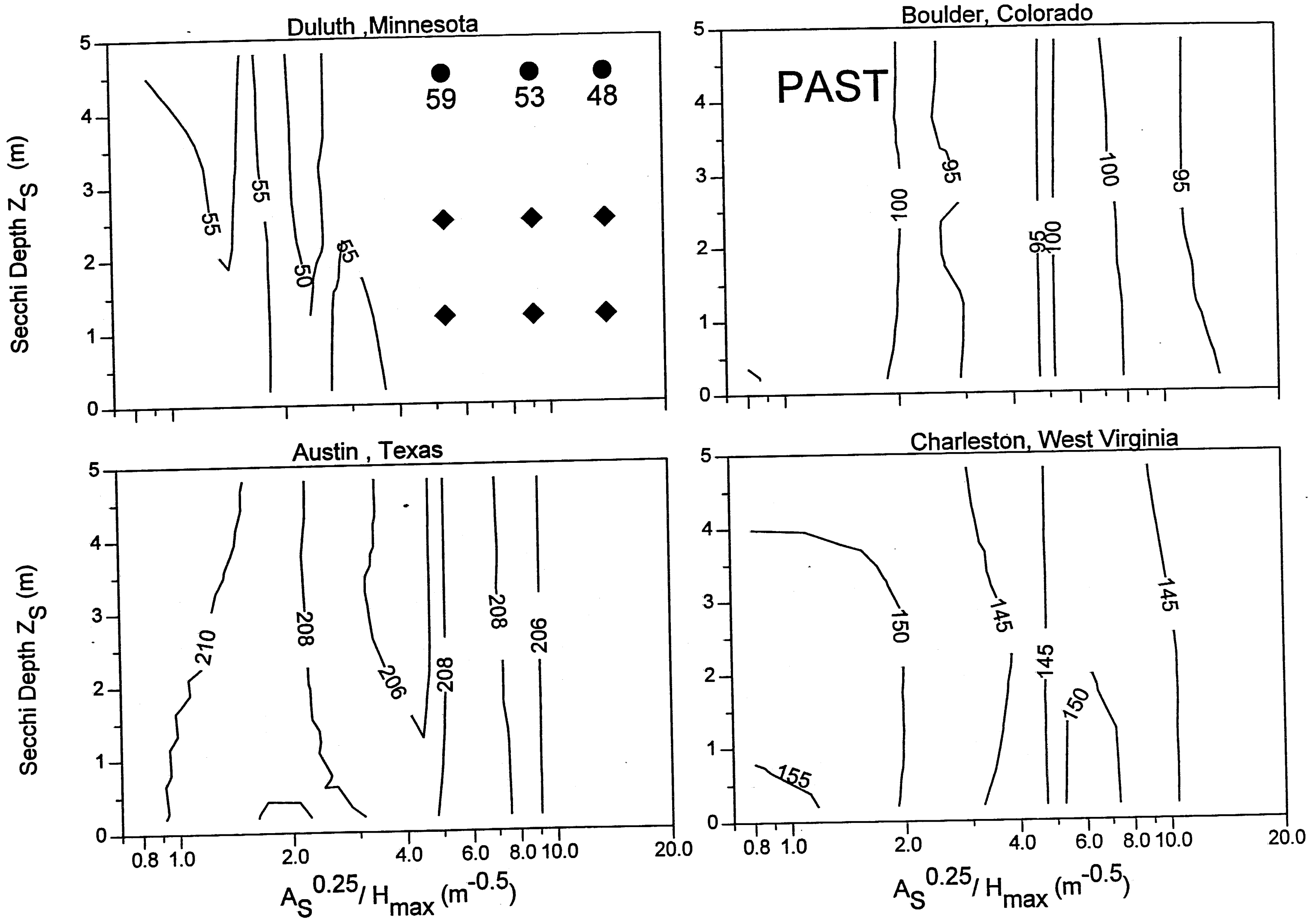

Fig. 18a Simulated **good-growth length (days)** for **warmwater fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled diamonds* are lakes with uninhabitable space during *the winter*.

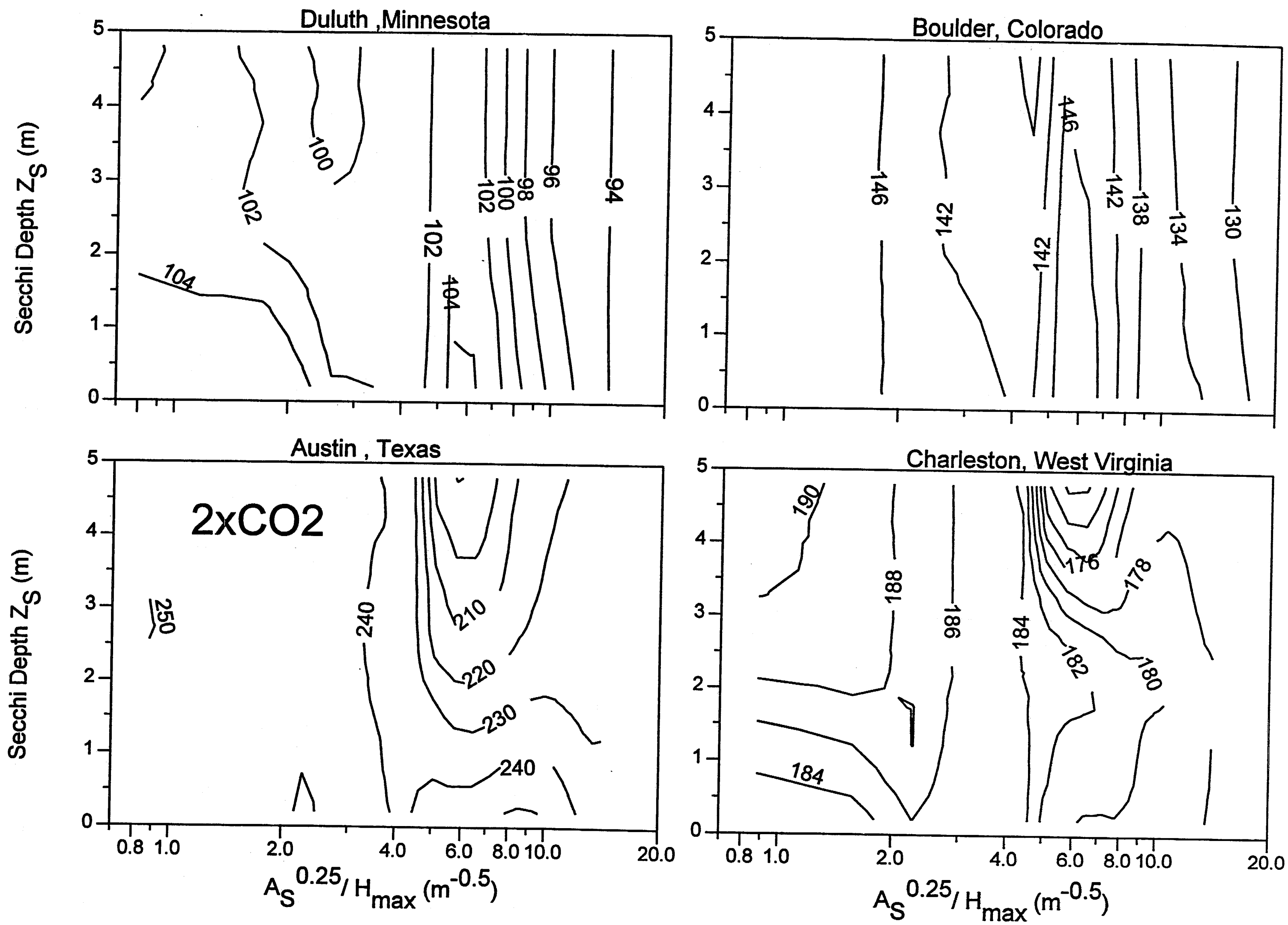

Fig. 18b Simulated **good-growth length (days)** for **warmwater fish** under **projected 2xCO_2 climate scenario** plotted as isopleths against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV).

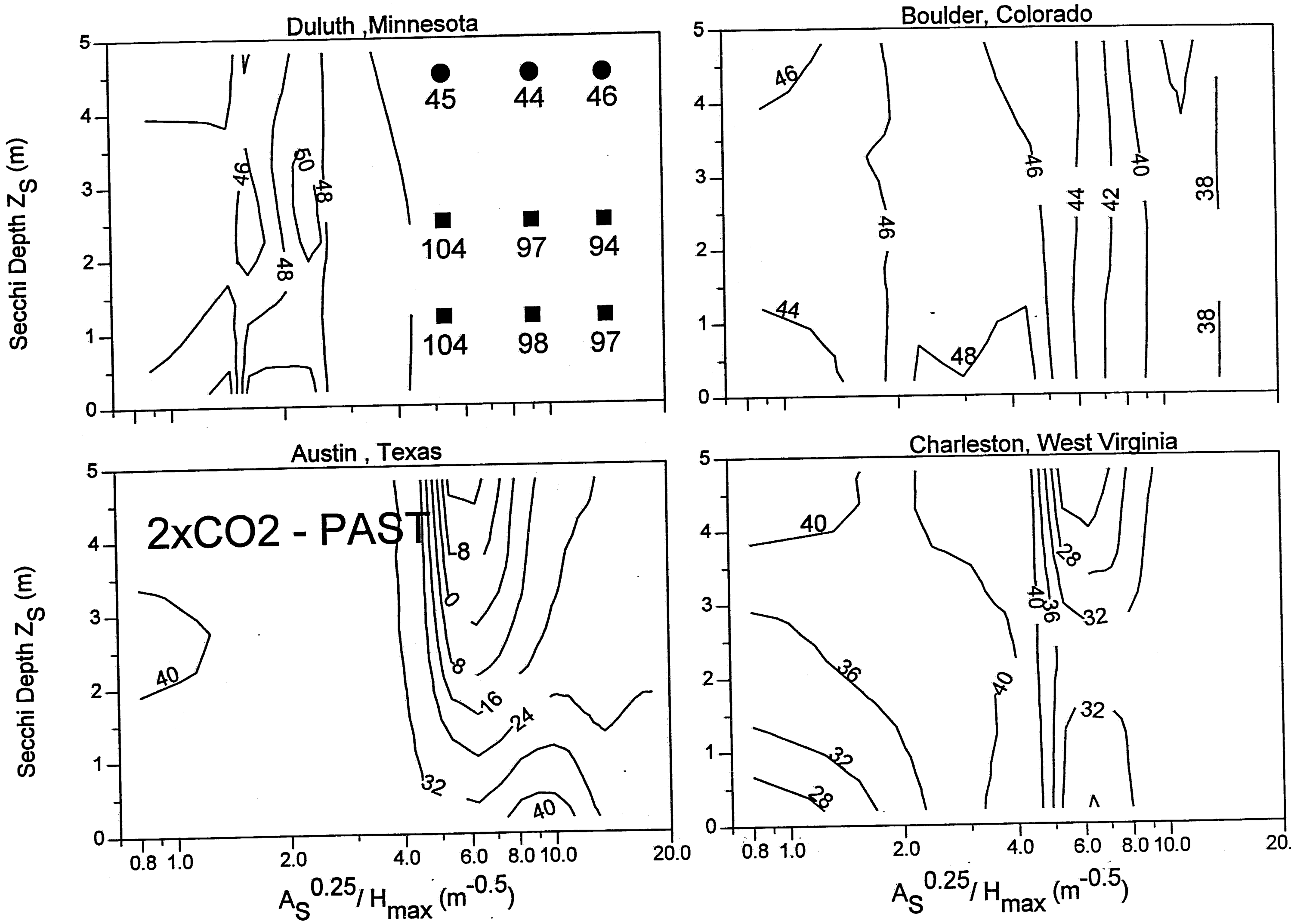

Fig. 18c **Differences** between projected and past climate conditions for simulated **good-growth length (days)** for **warmwater fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

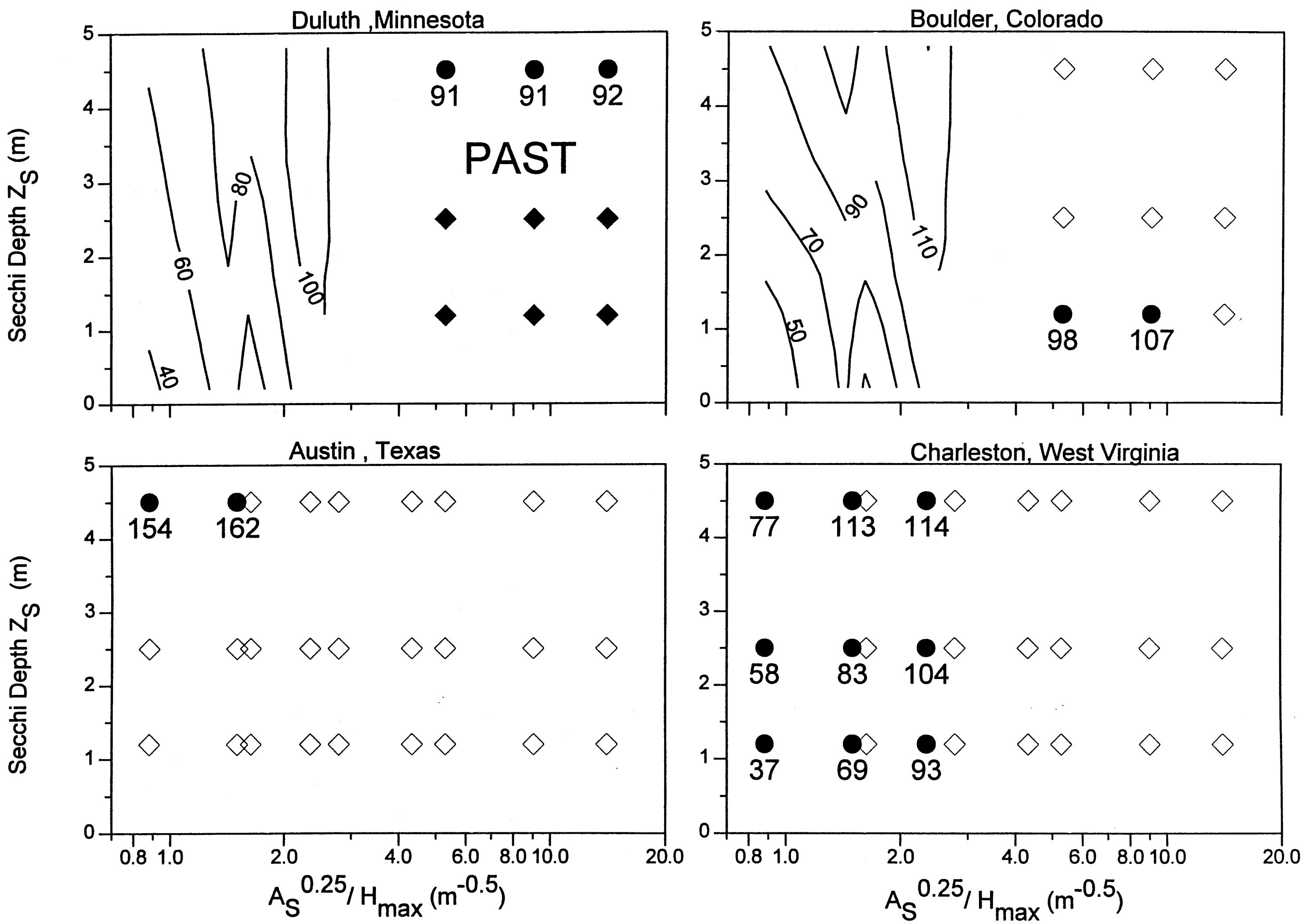

Fig. 19a Simulated, time-integrated and **normalized good-growth habitat areas** (days) for **cold-water fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled and open diamonds* are lakes with uninhabitable space during *the winter and the summer, respectively.*

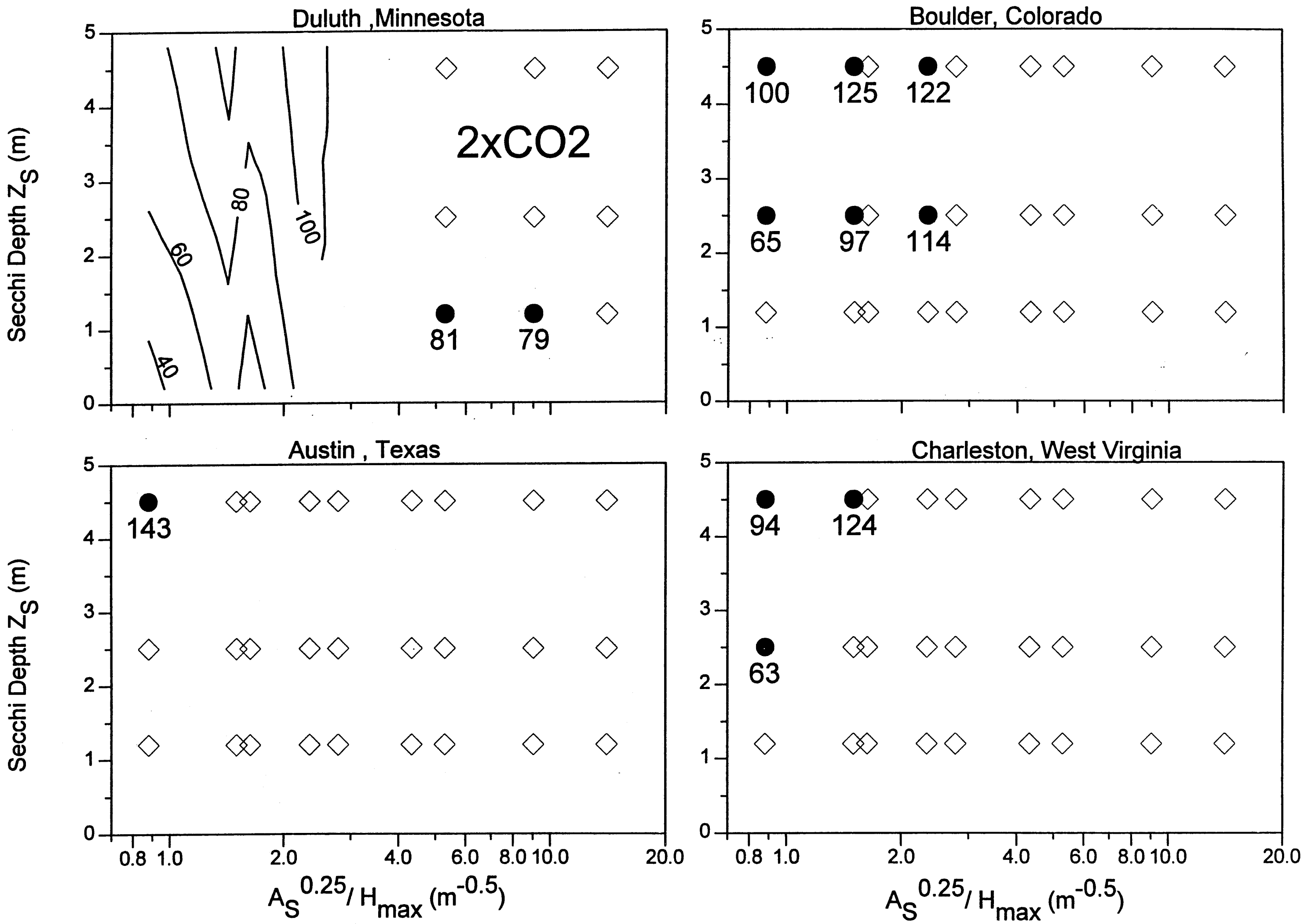

Fig. 19b Simulated, time-integrated and **normalized good-growth habitat areas** (days) for **cold-water fish** under **projected 2xCO_2 climate scenario** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Open diamonds* are lakes with uninhabitable space during *the summer*.

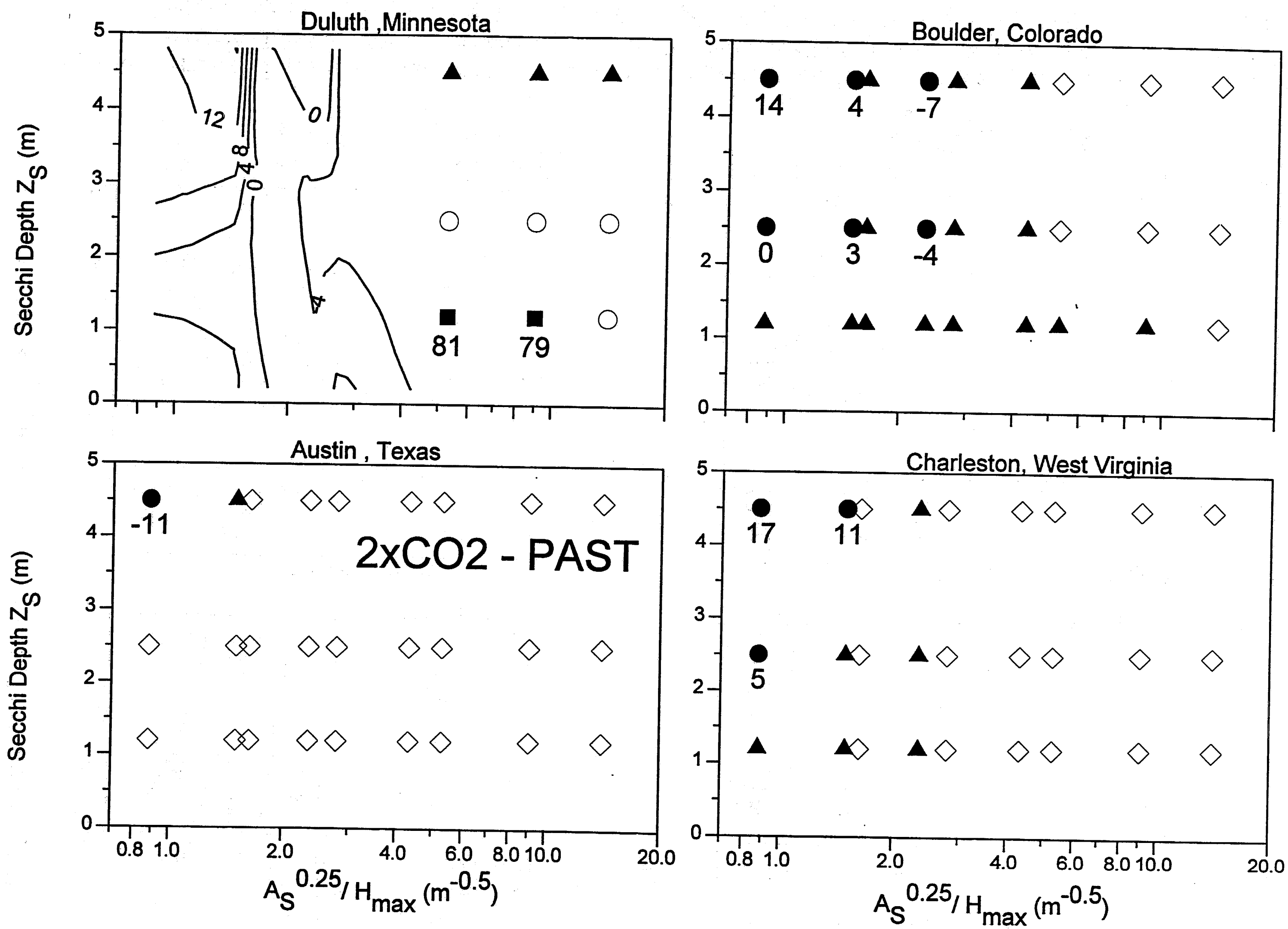

Fig. 19c **Differences** between projected and past climate conditions for simulated, time-integrated and **normalized good-growth habitat areas** (days) for **cold-water fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

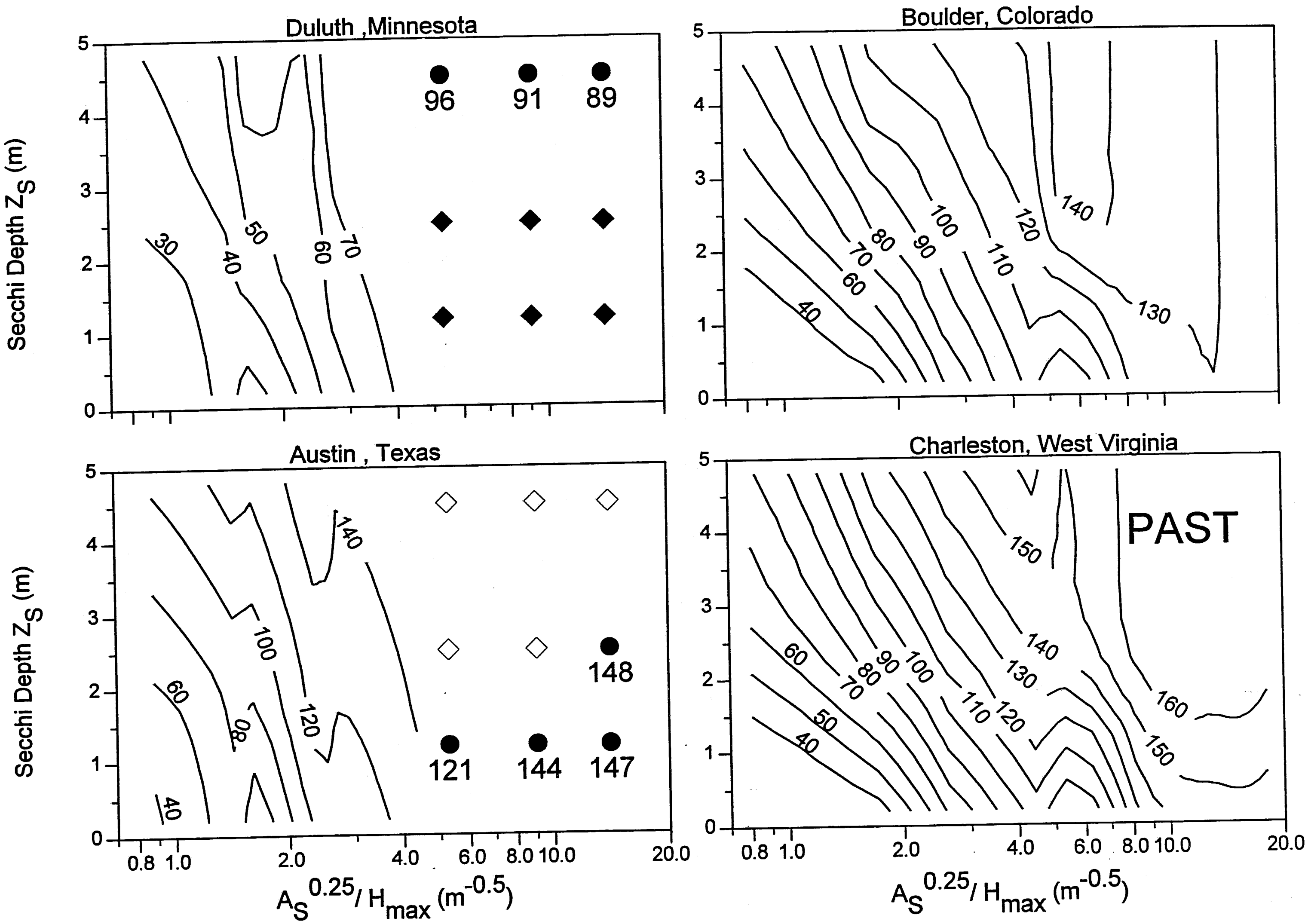

Fig. 20a Simulated, time-integrated and **normalized good-growth habitat areas** (days) for **cool-water fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled and open diamonds* are lakes with uninhabitable space during *the winter and the summer, respectively.*

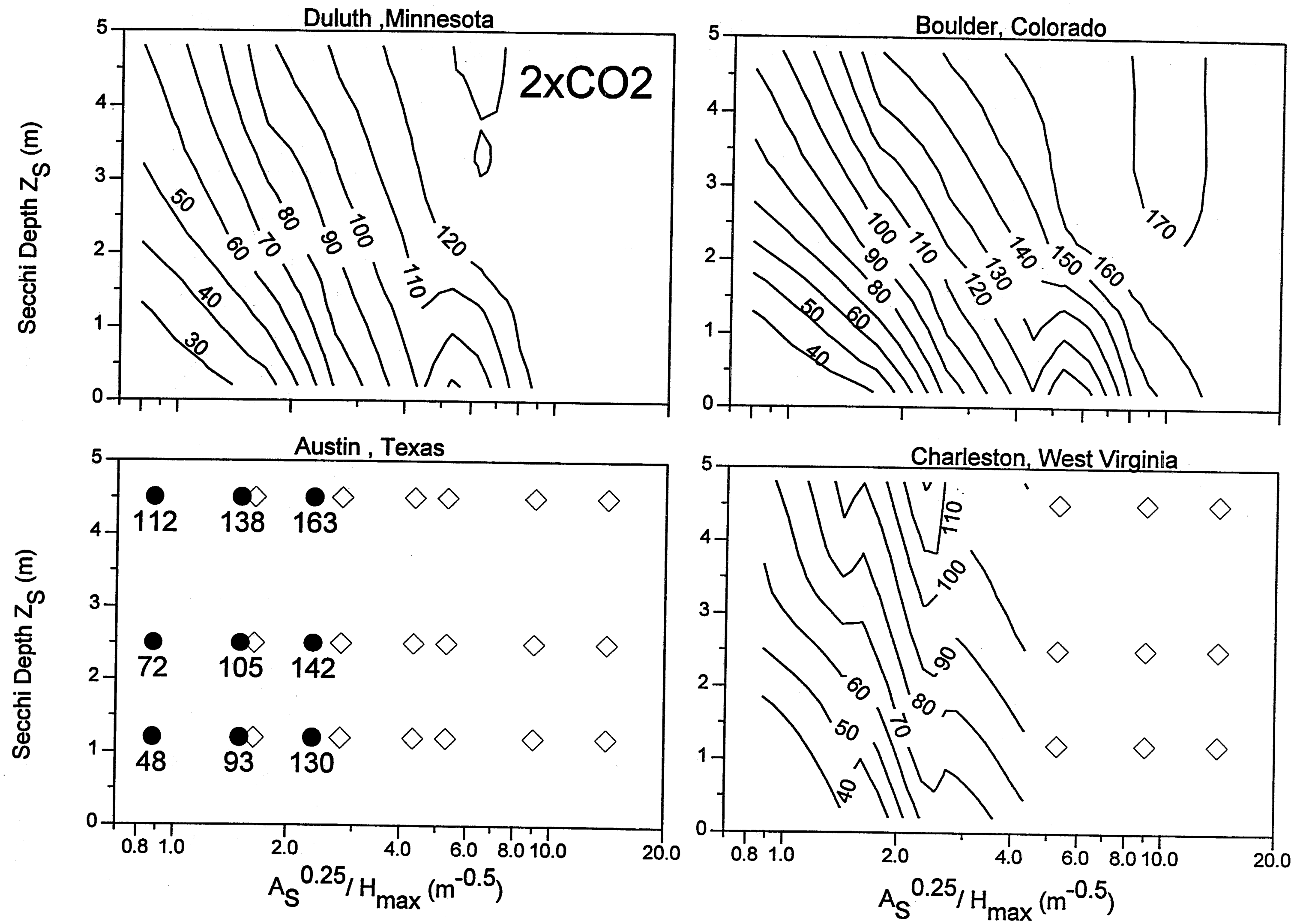

Fig. 20b Simulated, time-integrated and **normalized good-growth habitat areas** (days) for **cool-water fish** under **projected 2xCO_2 climate scenario** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Open diamonds* are lakes with uninhabitable space during *the summer*.

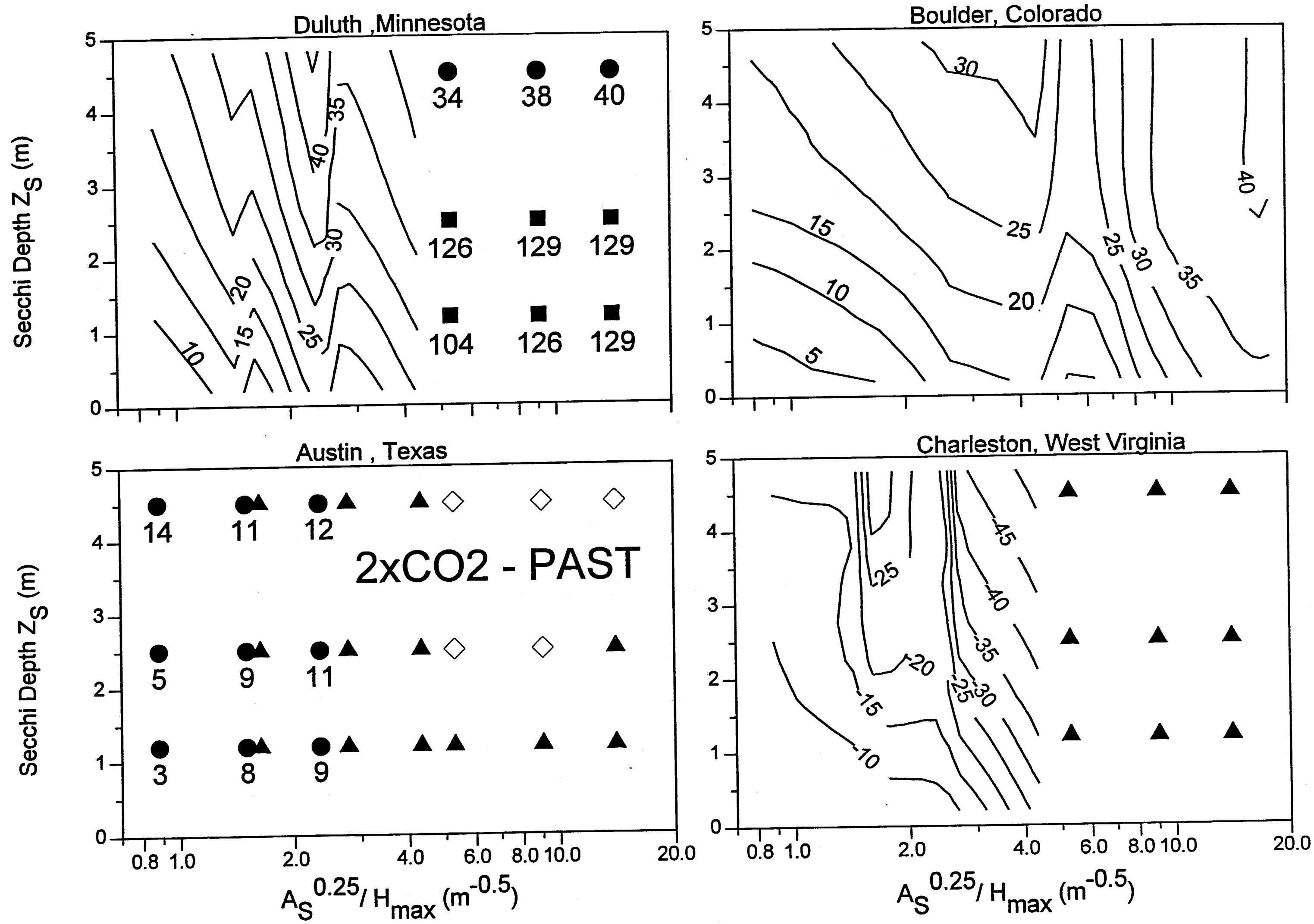

Fig. 20c **Differences** between projected and past climate conditions for simulated, time-integrated and **normalized good-growth habitat areas** (days) for **cool-water fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

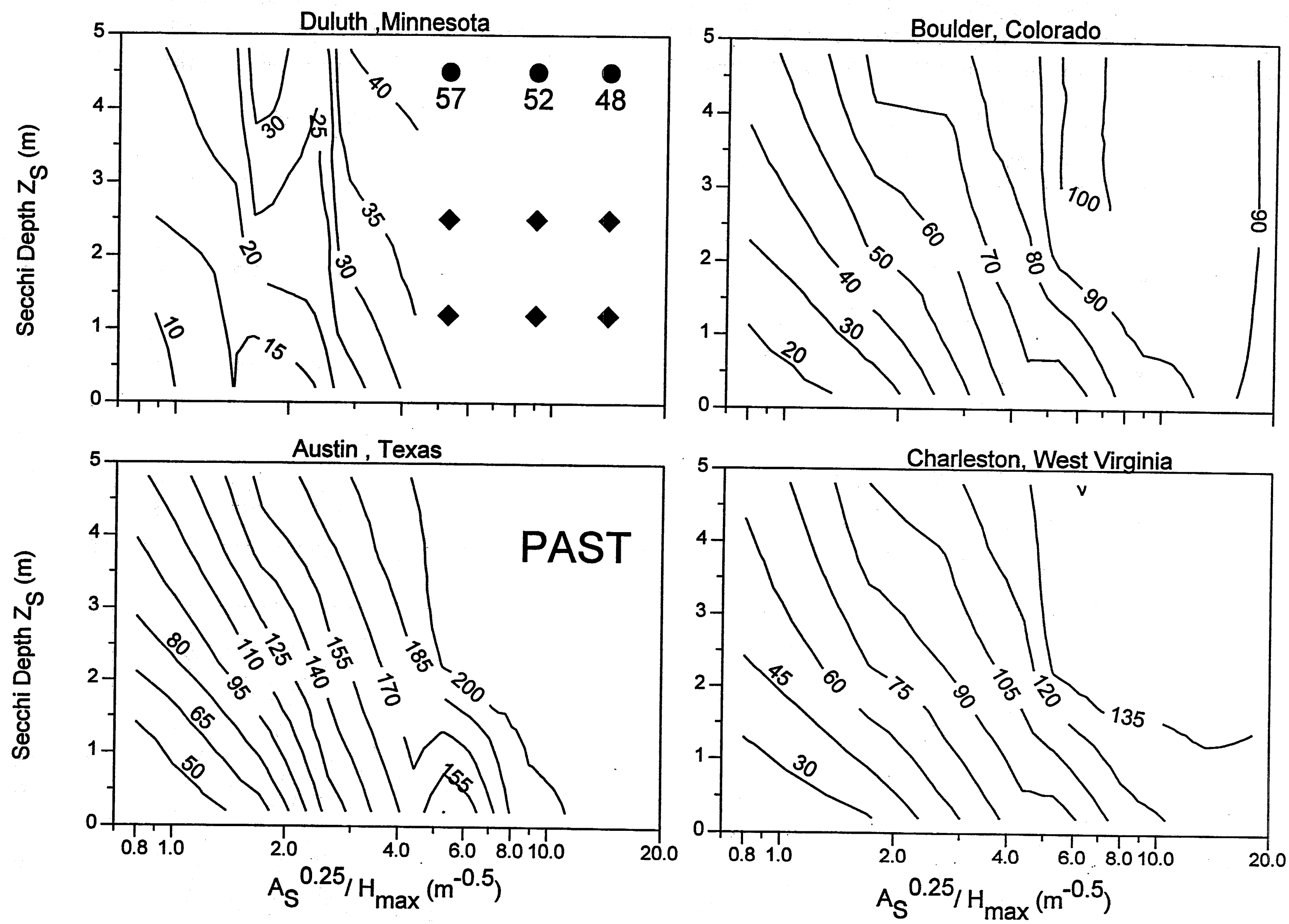

Fig. 21a Simulated, time-integrated and **normalized good-growth habitat areas** (days) for **warmwater fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled diamonds* are lakes with uninhabitable space during *the winter.*

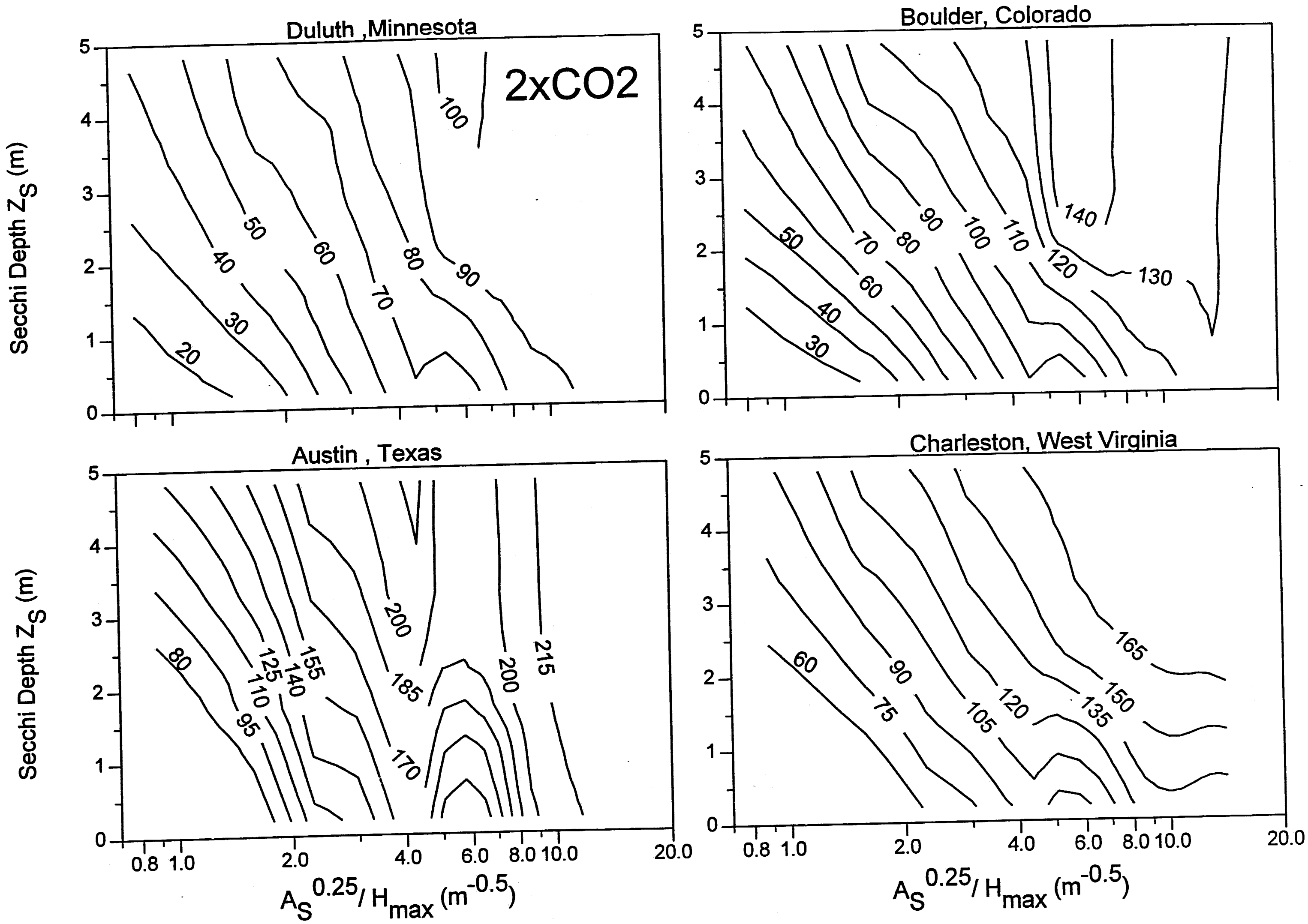

Fig. 21b Simulated, time-integrated and **normalized good-growth habitat areas** (days) for **warmwater fish** under **projected 2xCO_2 climate scenario** plotted as isopleths against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV).

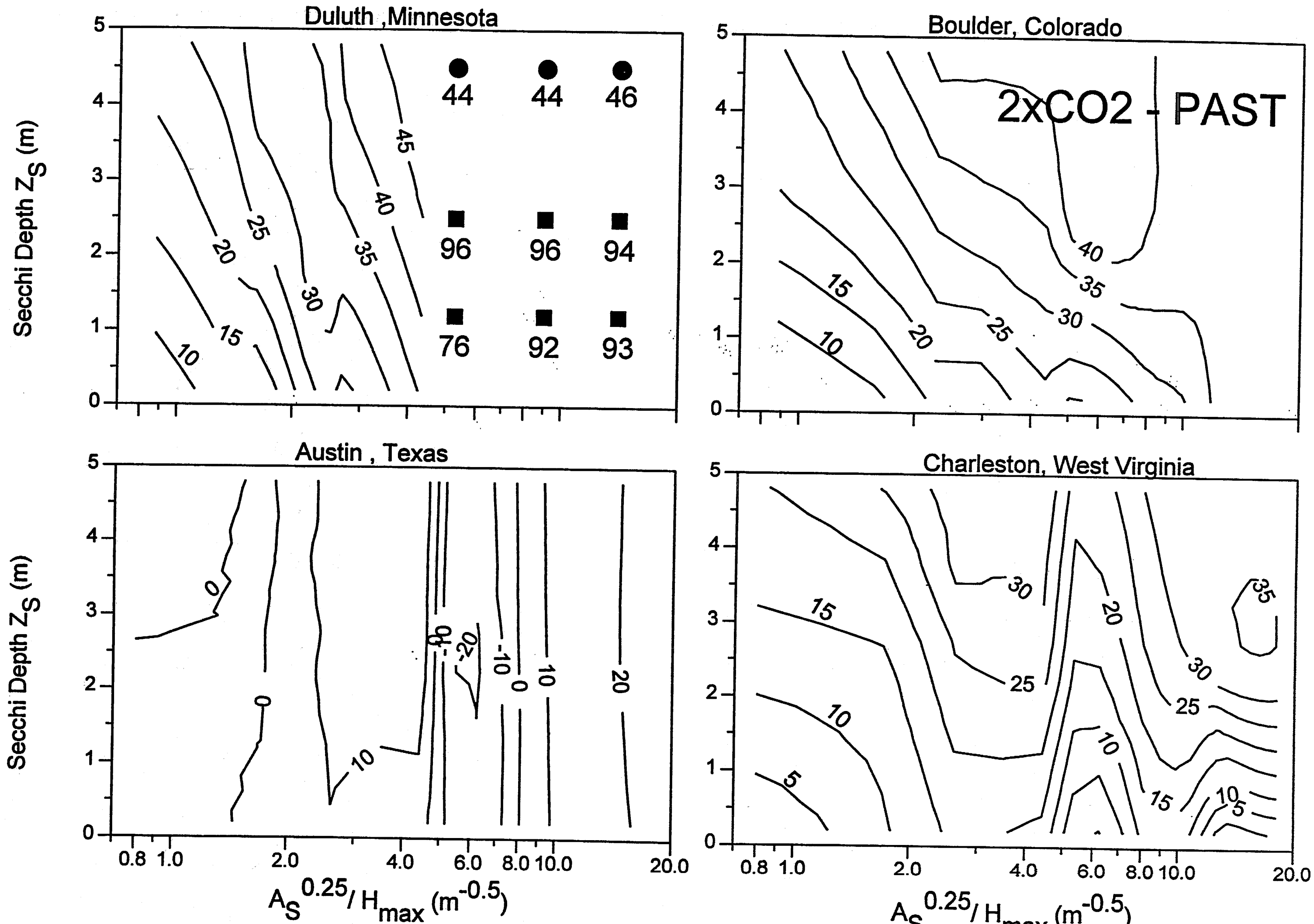

Fig. 21c **Differences** between projected and past climate conditions for simulated, time-integrated and **normalized good-growth habitat areas** (days) for **warmwater fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

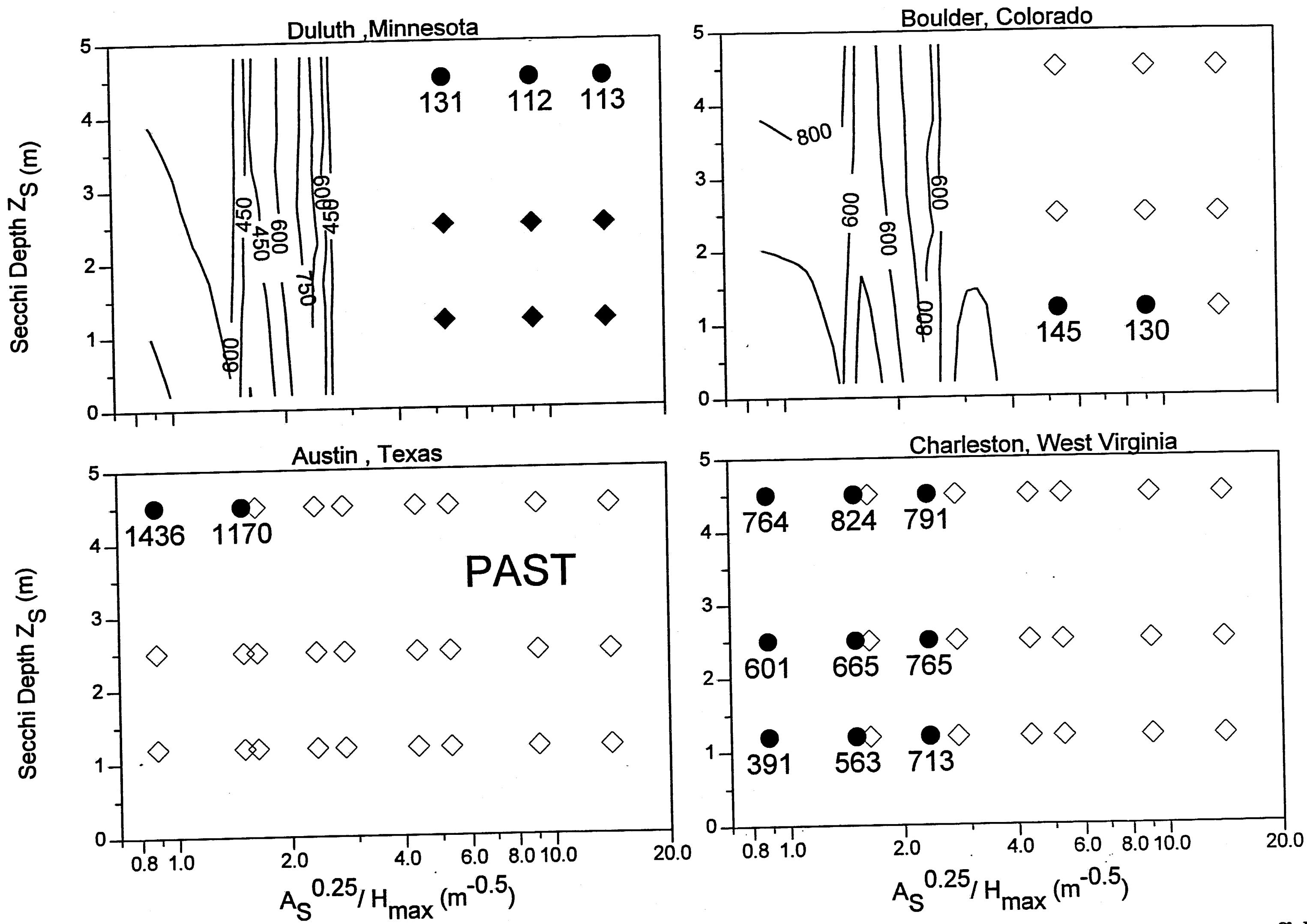

Fig. 22a Simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) for **cold-water fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled and open diamonds* are lakes with uninhabitable space during *the winter and the summer, respectively*.

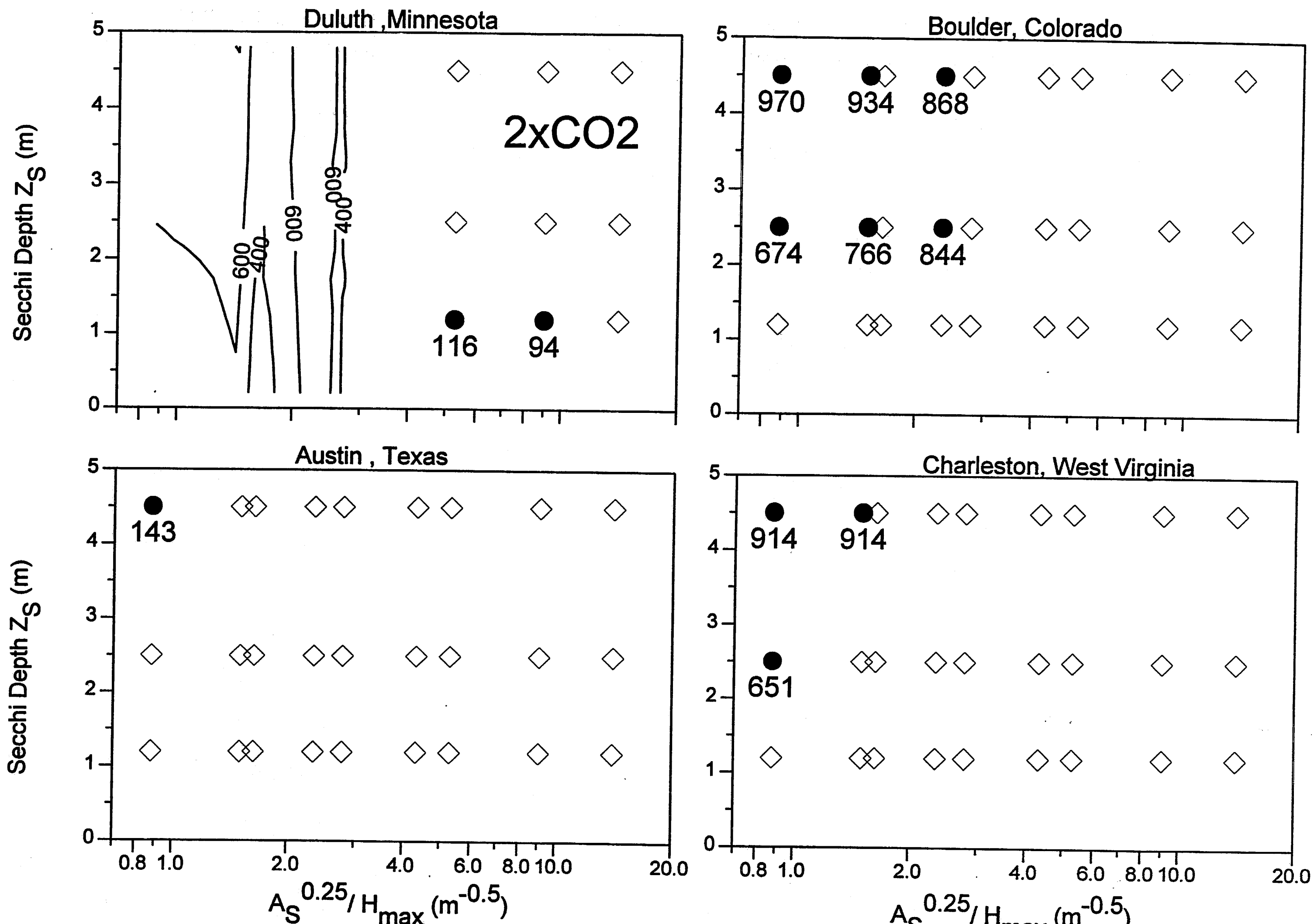

Fig. 22b Simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) for **cold-water fish** under **projected 2xCO_2 climate scenario** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Open diamonds* are lakes with uninhabitable space during *the summer*.

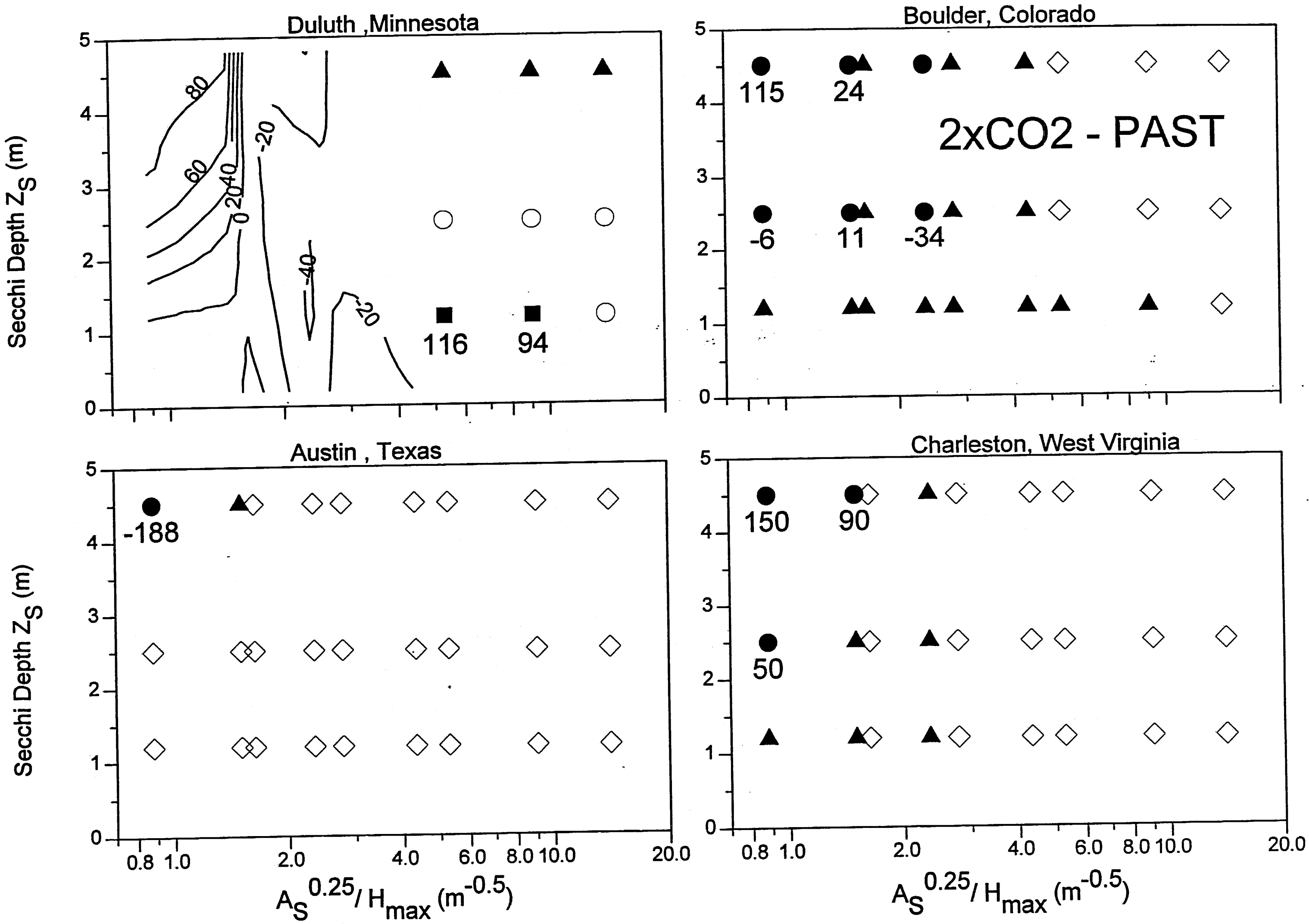

Fig. 22c **Differences** between projected and past climate conditions for simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) for **cold-water fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

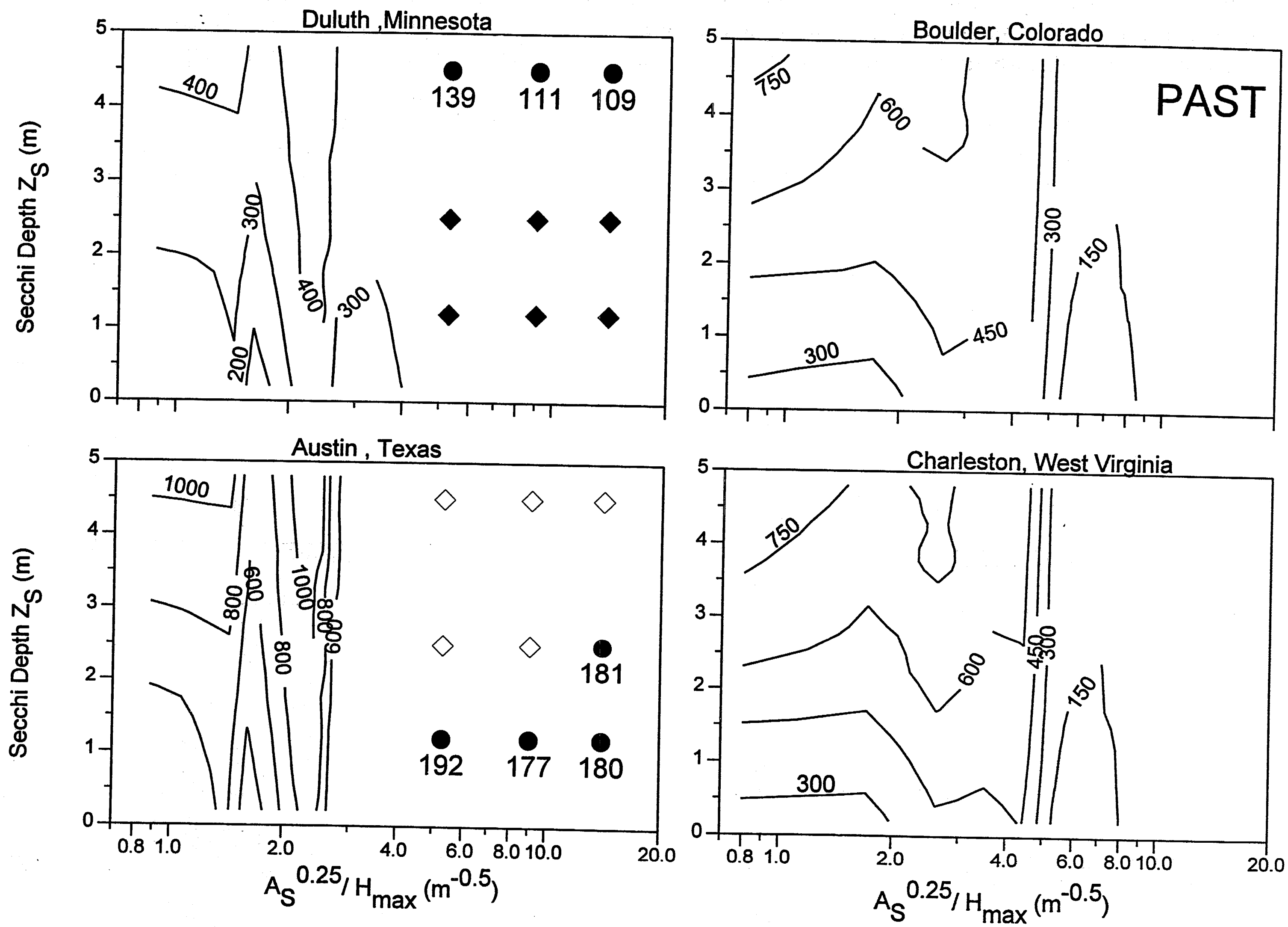

Fig. 23a Simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) for **cool-water fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled and open diamonds* are lakes with uninhabitable space during *the winter and the summer, respectively.*

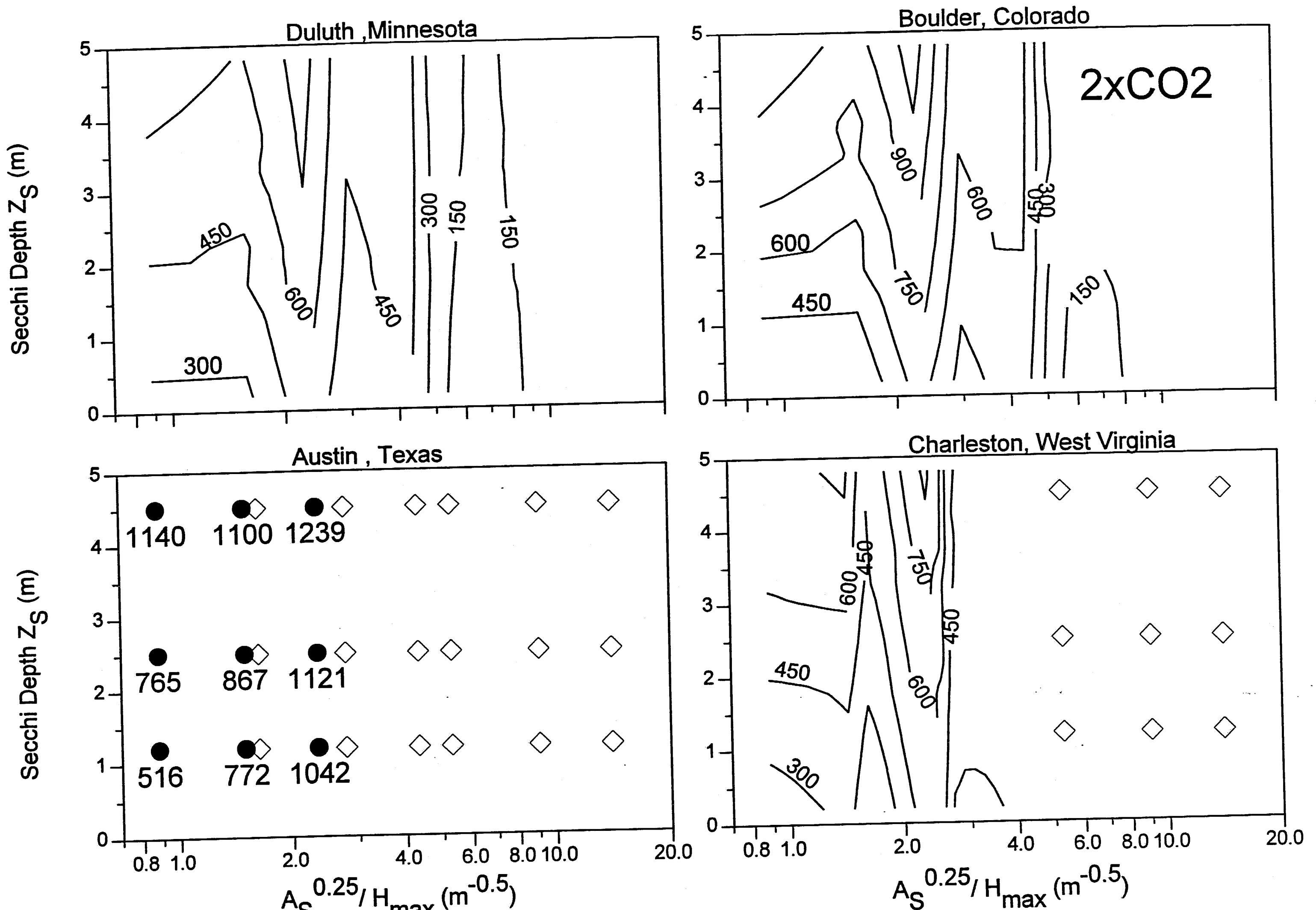

Fig. 23b Simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) for **cool-water fish** under **projected 2xCO_2 climate scenario** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Open diamonds* are lakes with uninhabitable space during *the summer*.

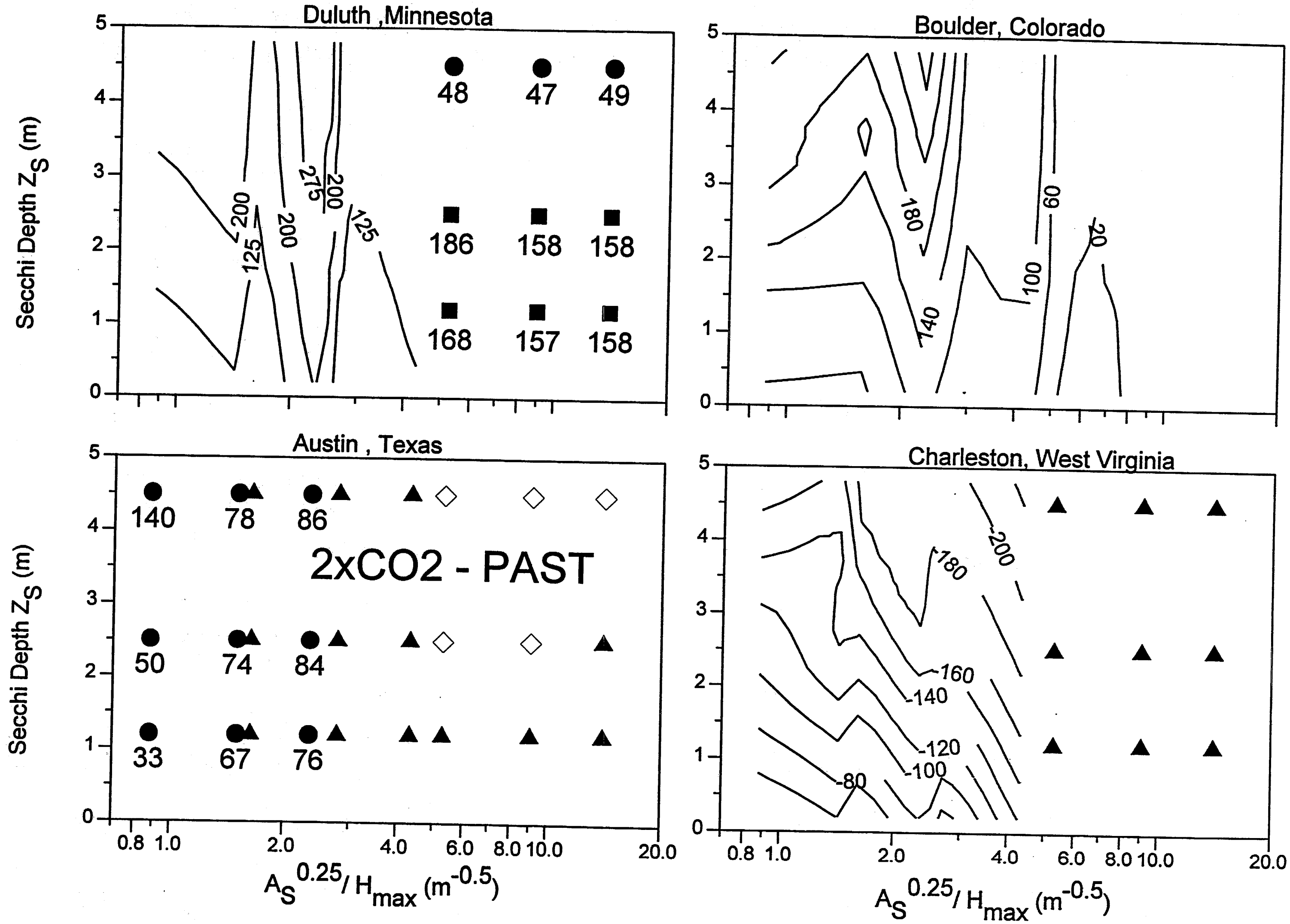

Fig. 23c **Differences** between projected and past climate conditions for simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) for **cool-water fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

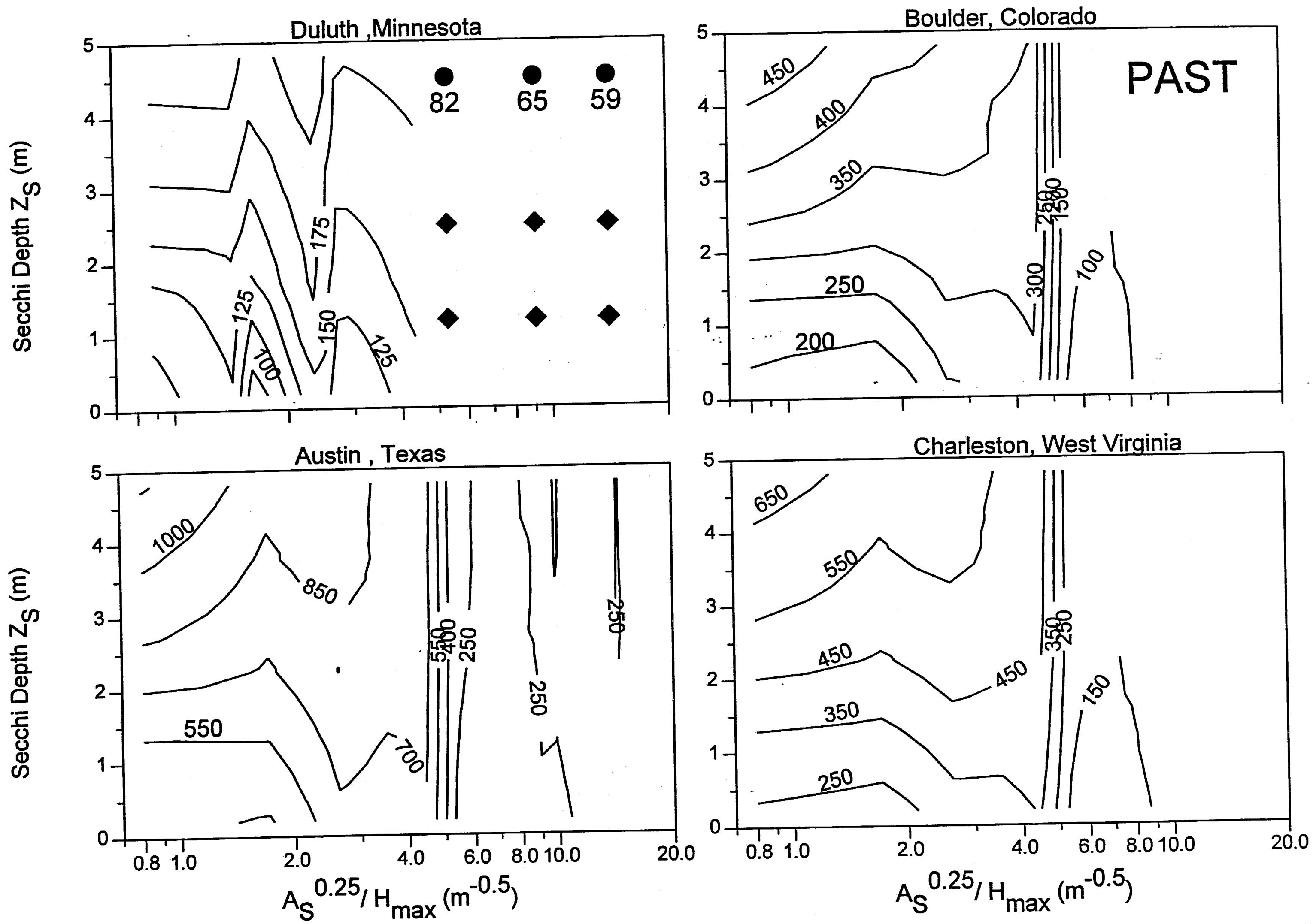

Fig. 24a Simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) for **warmwater fish** under **past climate conditions** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). *Filled diamonds* are lakes with uninhabitable space during *the winter*.

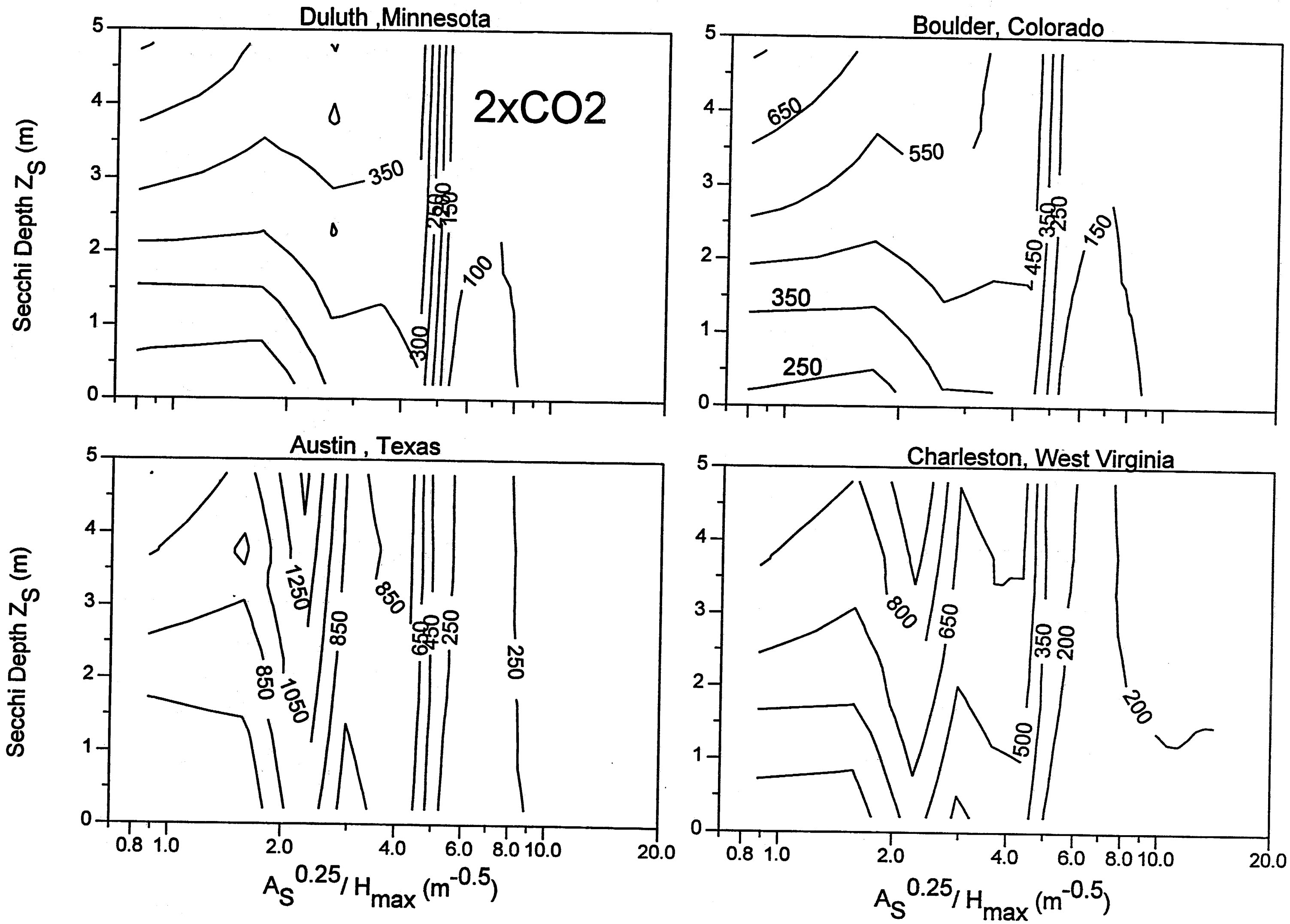

Fig. 24b Simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) for **warmwater fish** under **projected 2xCO_2 climate scenario** plotted as isopleths against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV).

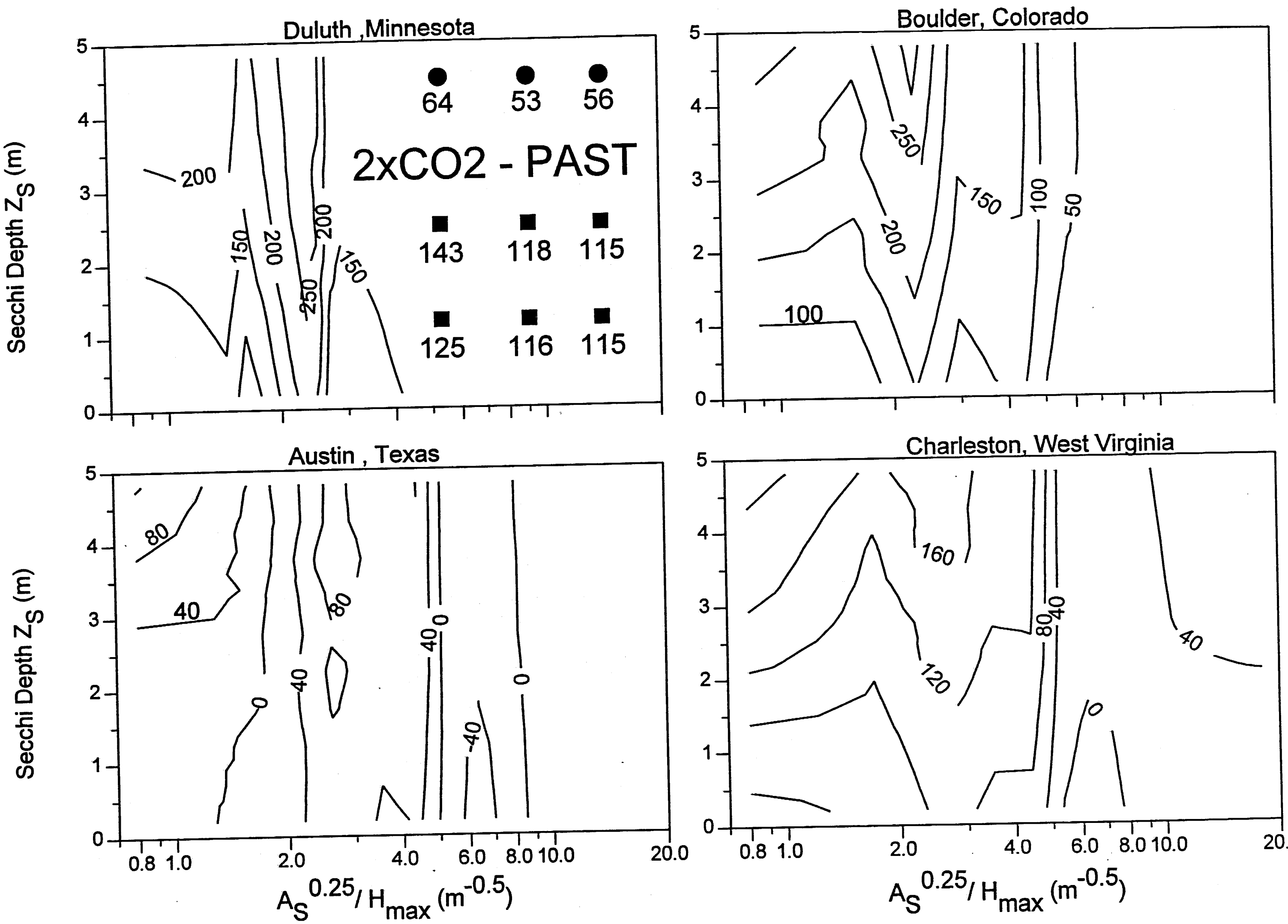

Fig. 24c **Differences** between projected and past climate conditions for simulated, time-integrated and **normalized good-growth habitat volumes** (m-days) of **warmwater fish** plotted as isopleths or filled circles against two lake parameters at four climate stations (Duluth, MN, Boulder, CO, Austin, TX, and Charleston, WV). Symbols used are defined in Table 18.

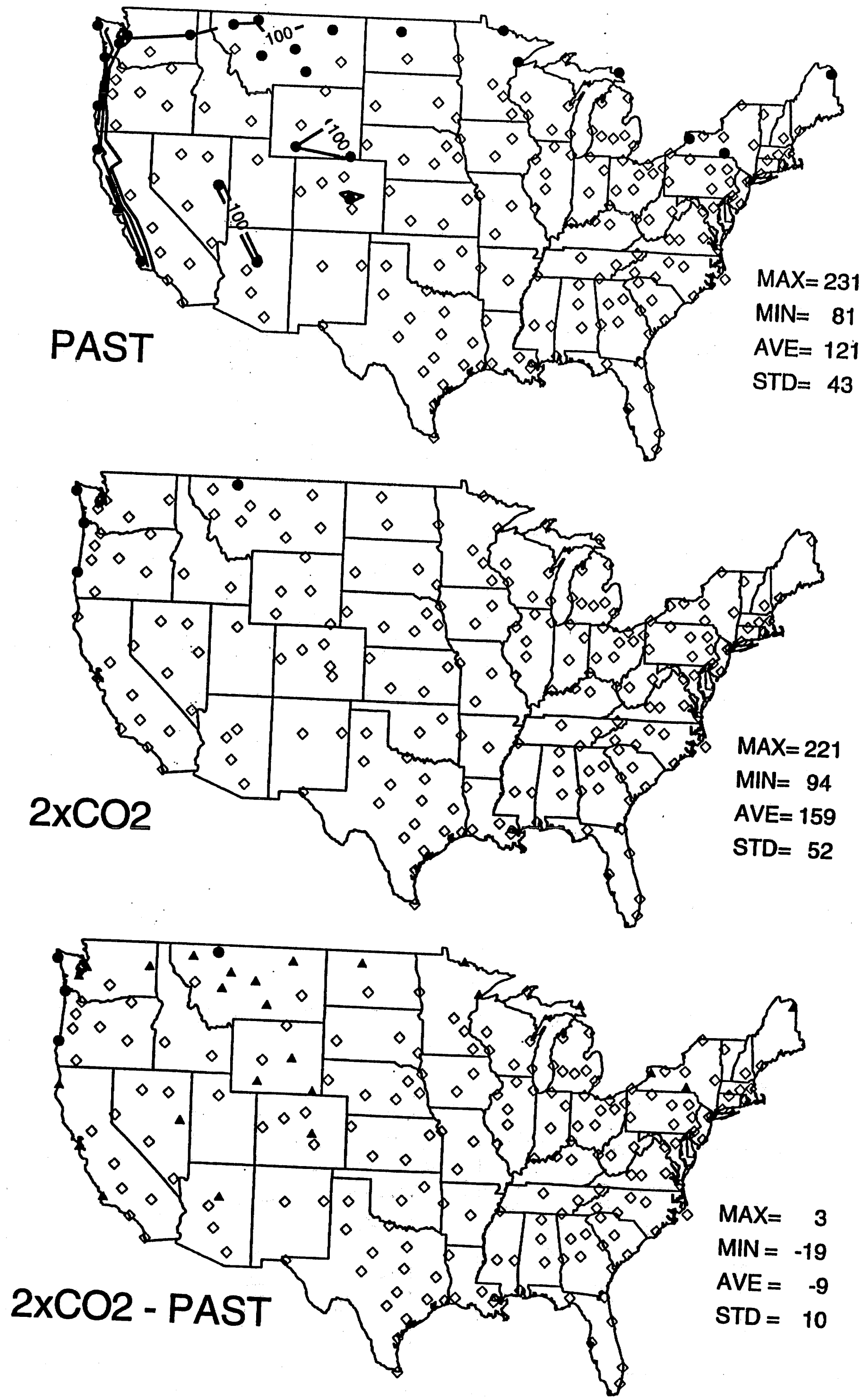

Fig. 25a Simulated **good-growth period (days)** of **cold-water fish** in *oligotrophic, shallow, large lakes (Type 9, A_s=10 km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

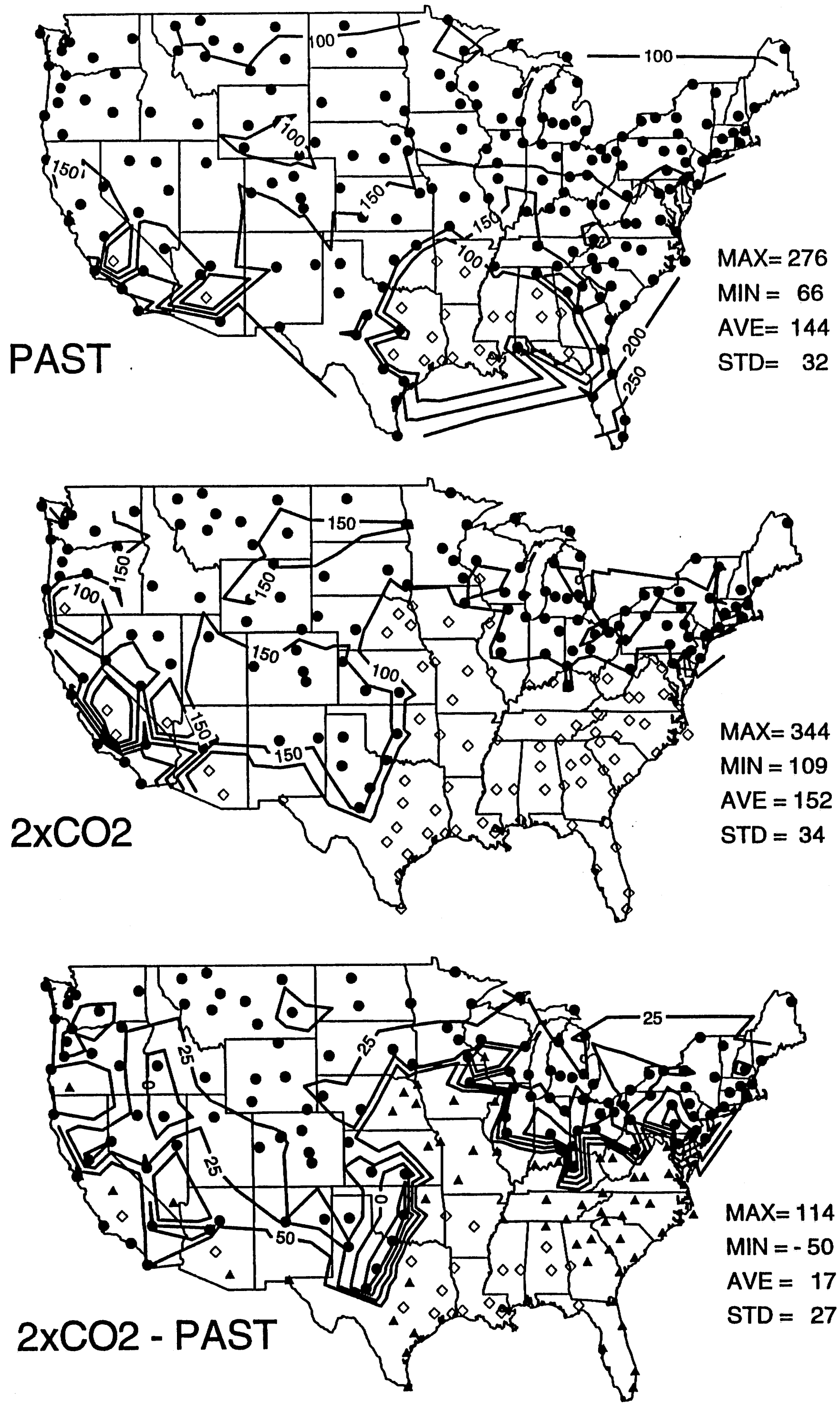

Fig. 25b Simulated **good-growth period (days)** of **cool-water fish** in *oligotrophic, shallow, large lakes (Type 9,* A_s*=10 km*^{2}*)* under past (1962-1979)(top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

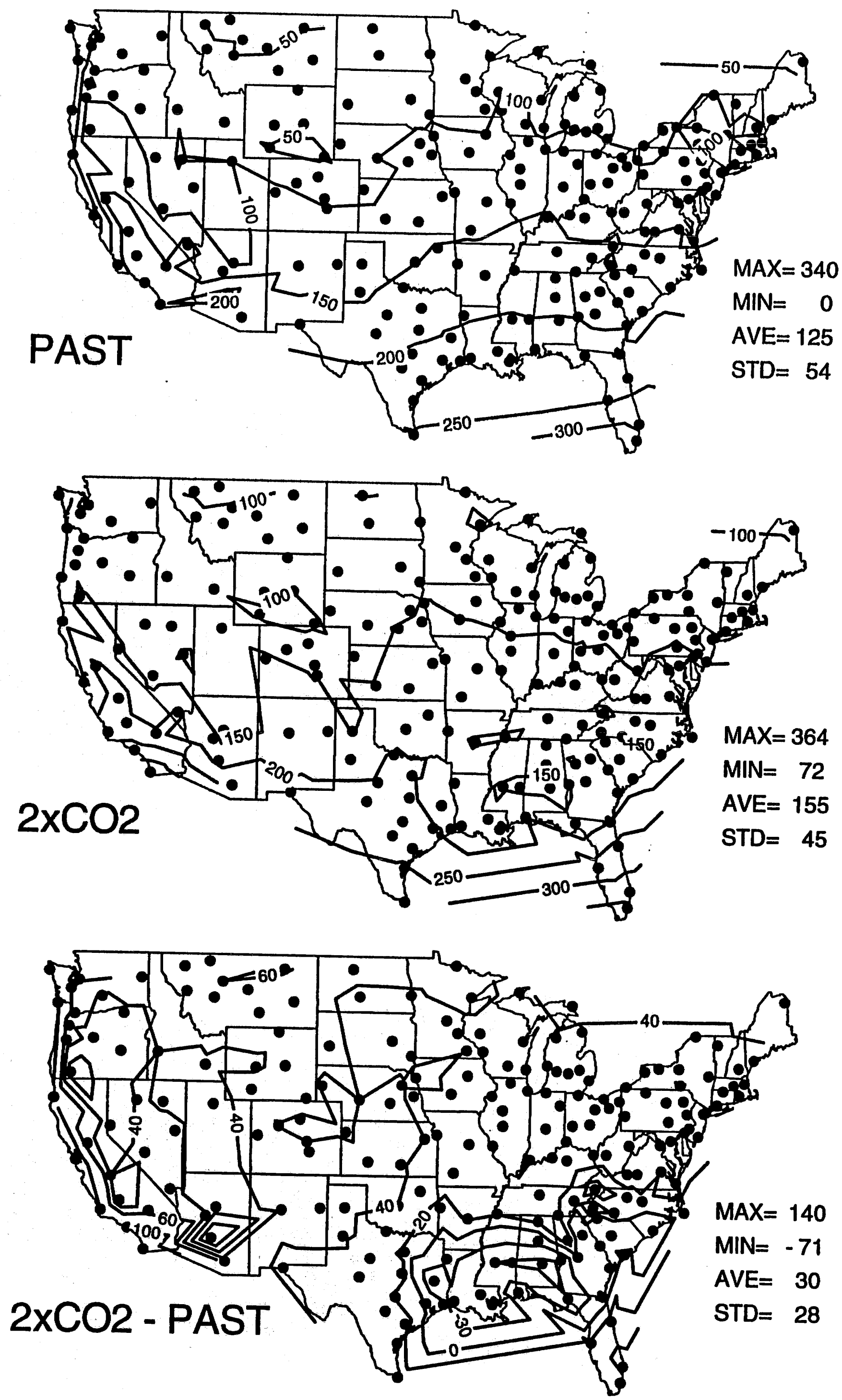

Fig. 25c Simulated **good-growth period (days)** of **warmwater fish** in *oligotrophic, shallow, large lakes (Type 9, A_s=10km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

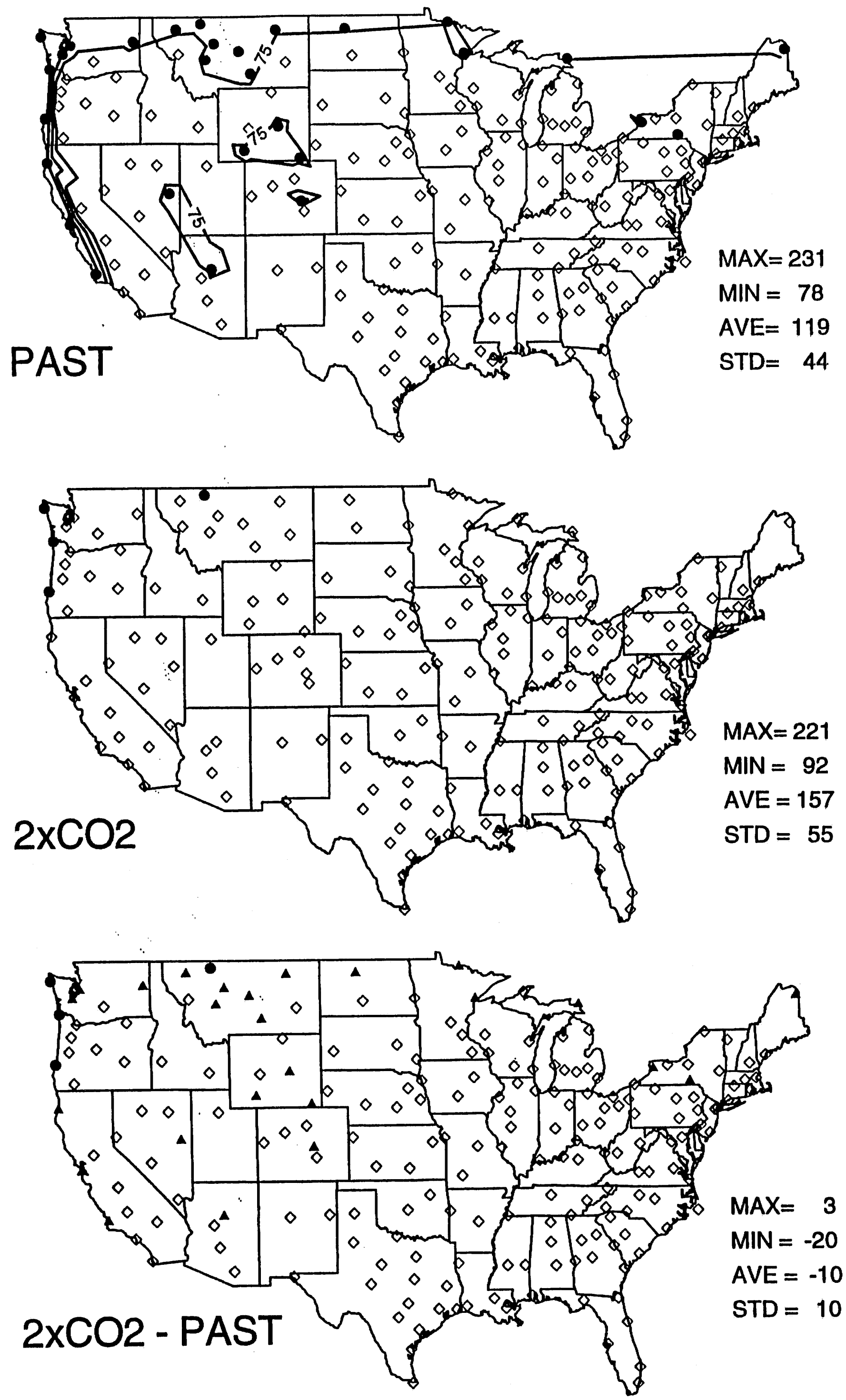

Fig. 26a Simulated **good-growth period (days)** of **cold-water fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10 km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

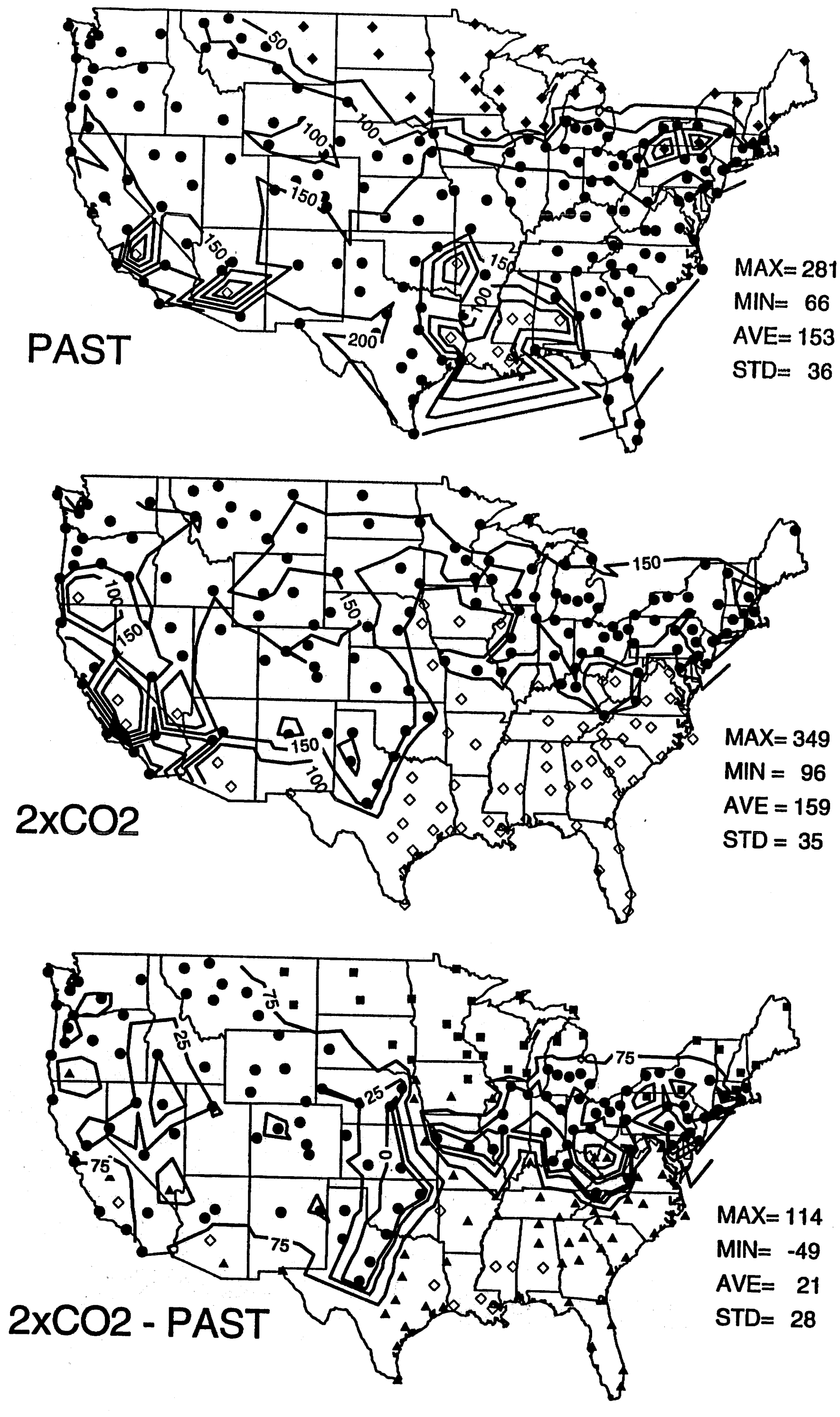

Fig. 26b Simulated **good-growth period (days)** of **cool-water fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10 km^2)* under past (1962-1979)(top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

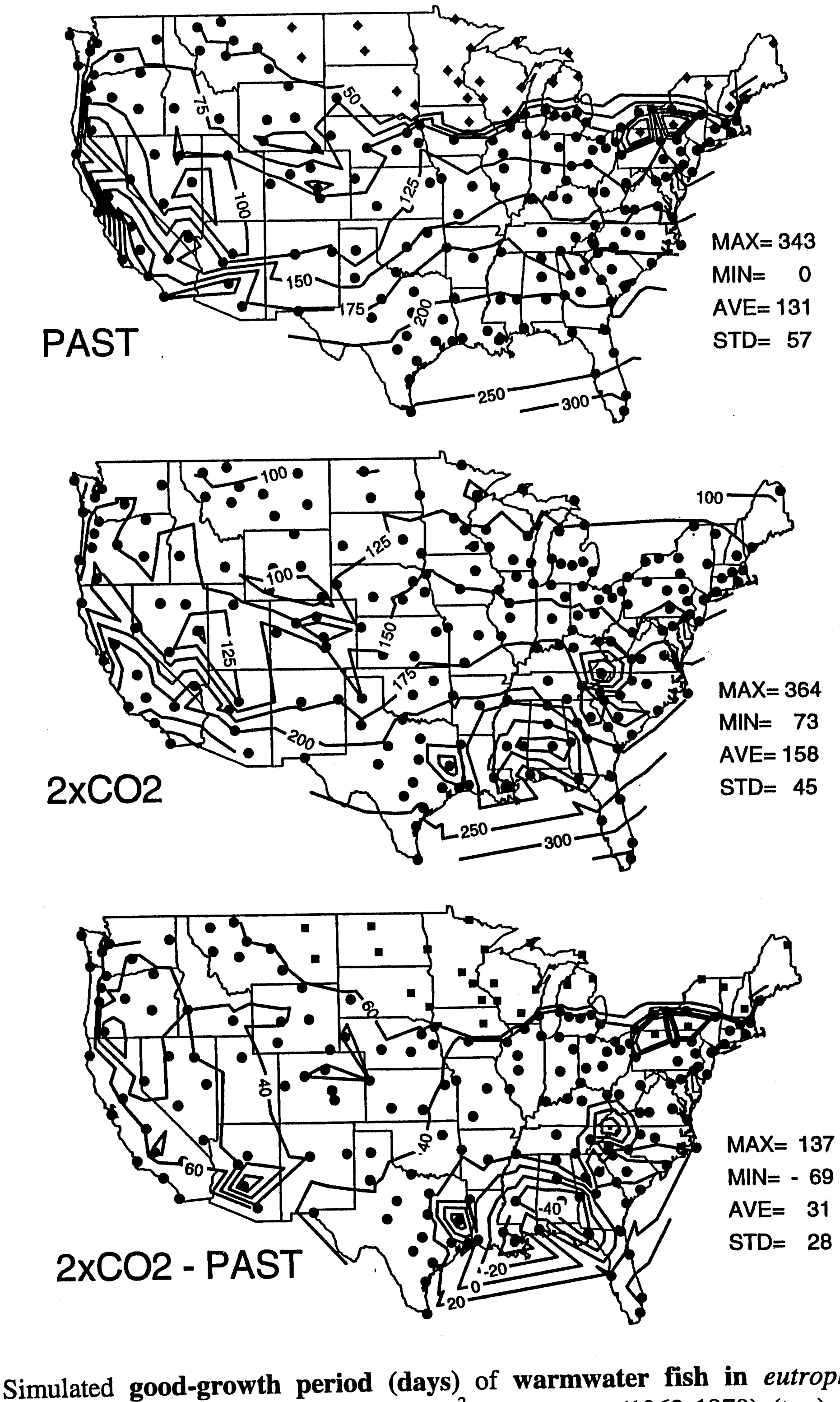

Fig. 26c Simulated **good-growth period (days)** of **warmwater fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10km²)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

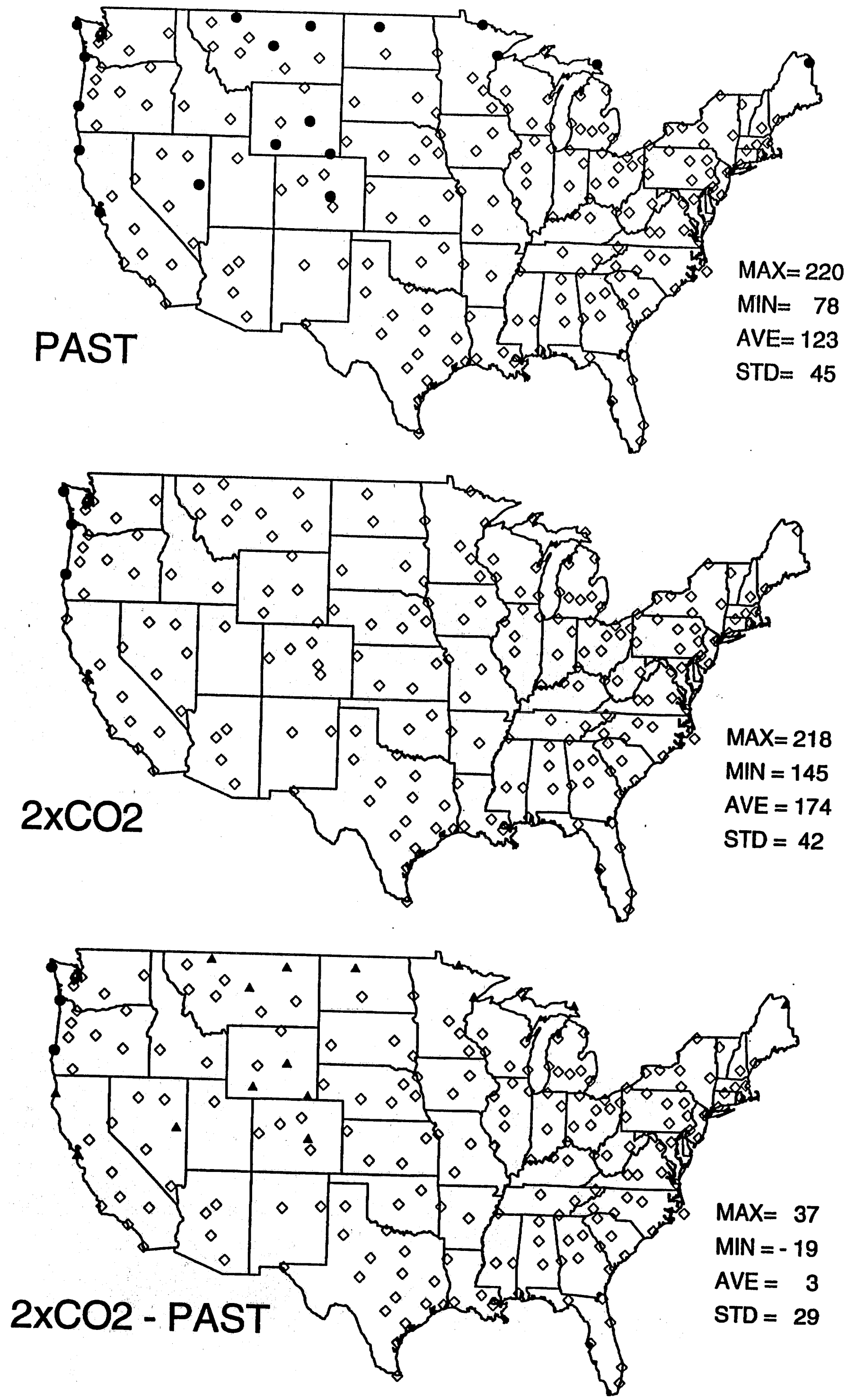

Fig. 27a Simulated **good-growth period (days)** of **cold-water fish in** *oligotrophic, shallow, small lakes (Type 3, A_s=0.2 km²)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

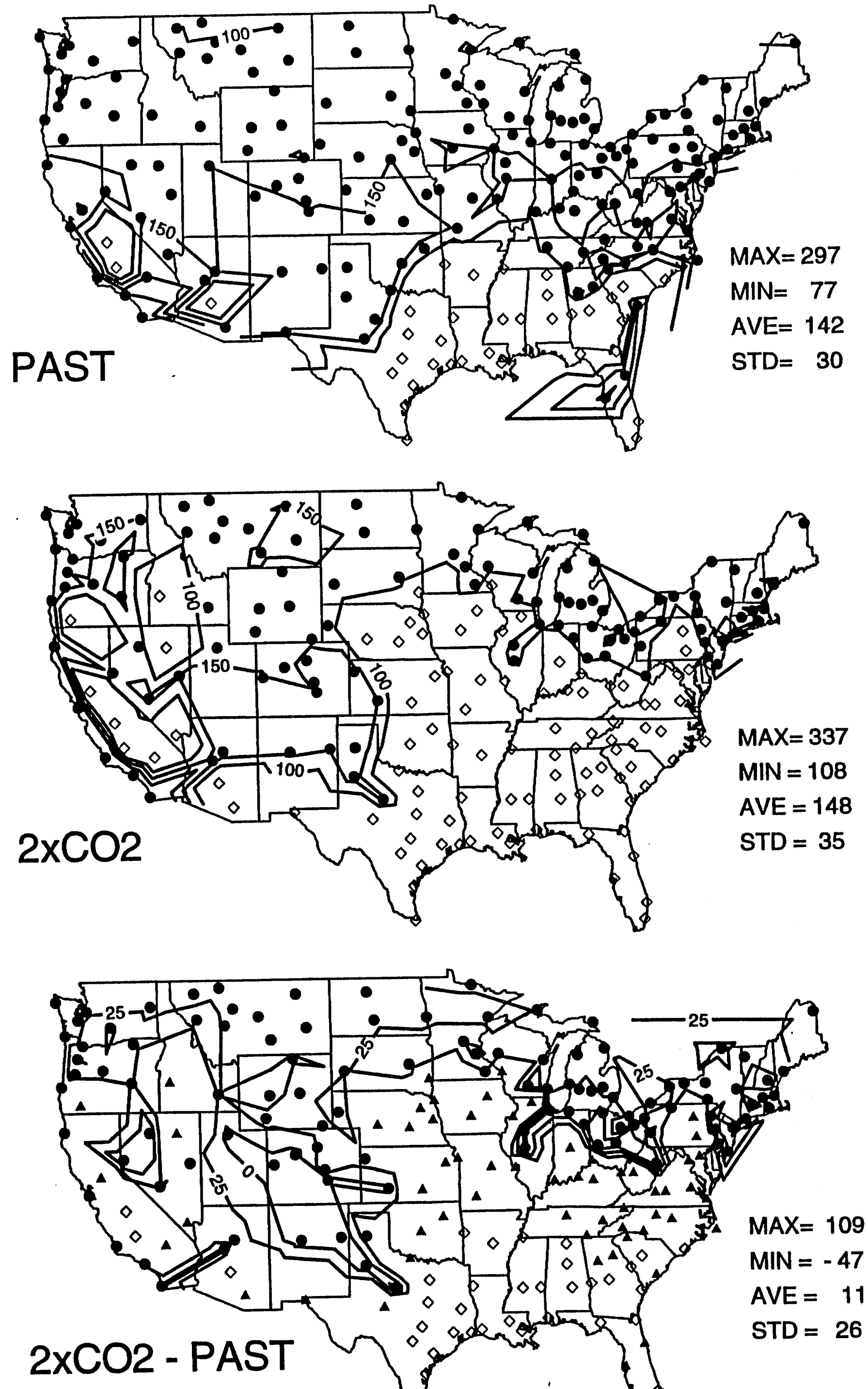

Fig. 27b Simulated **good-growth period (days)** of **cool-water fish in** *oligotrophic, shallow, small lakes (Type 3, A_s=0.2 km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

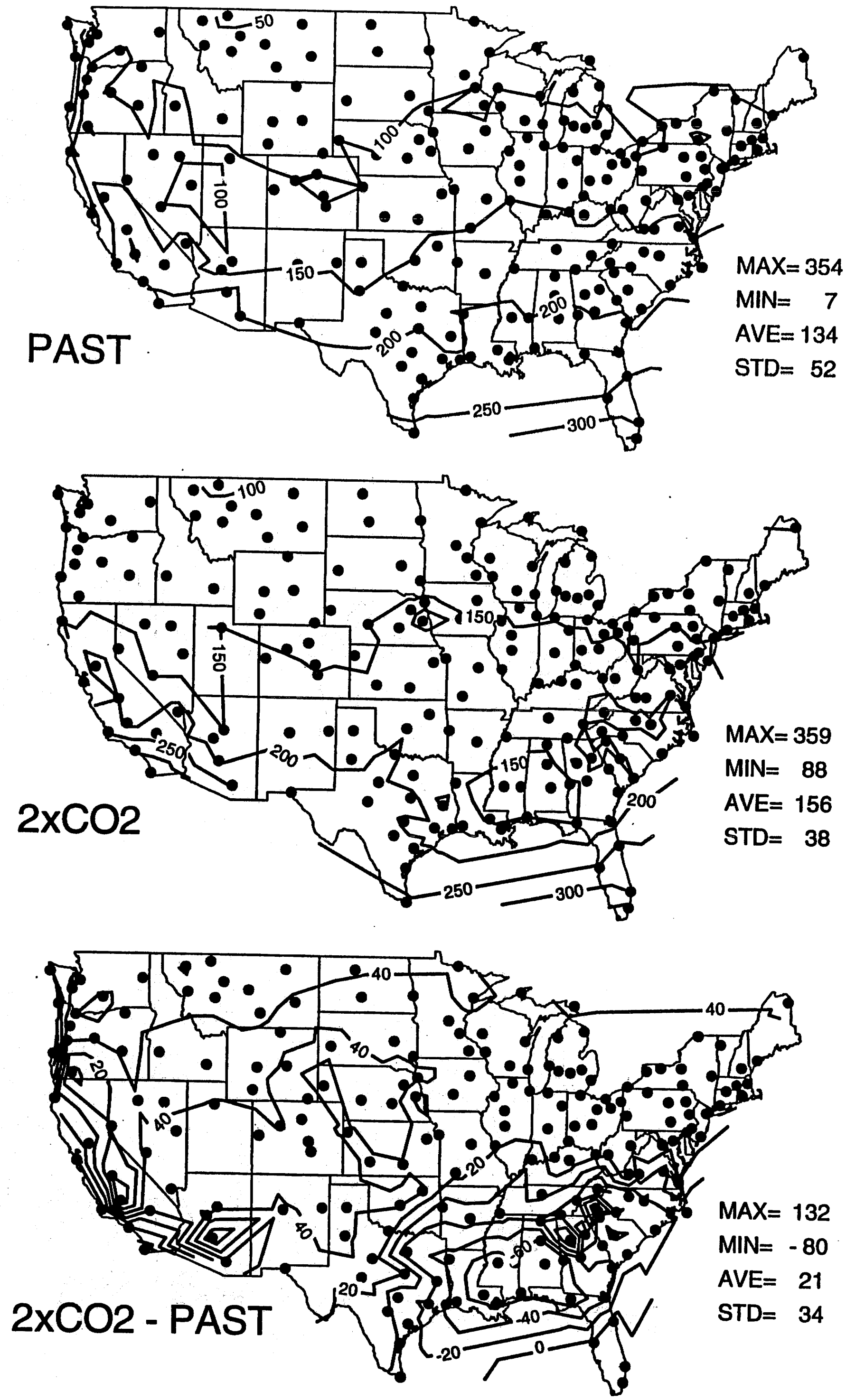

Fig. 27c Simulated **good-growth period (days)** of **warmwater fish in** *oligotrophic, shallow, small lakes (Type 3, A_s=0.2 km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

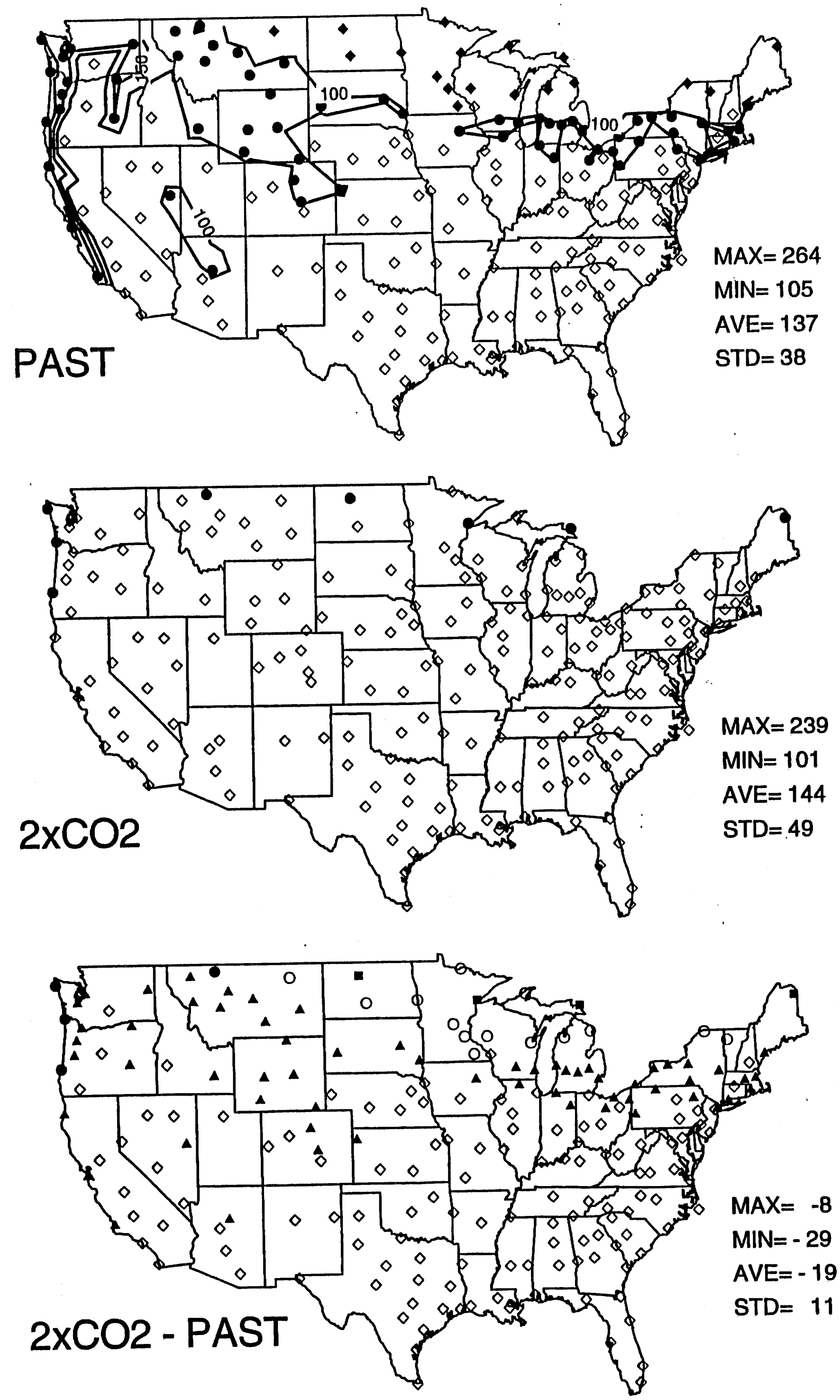

Fig. 28a Simulated **good-growth period (days)** of **cold-water fish in** *eutrophic, shallow, small lakes (Type 1, A_s=0.2 km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

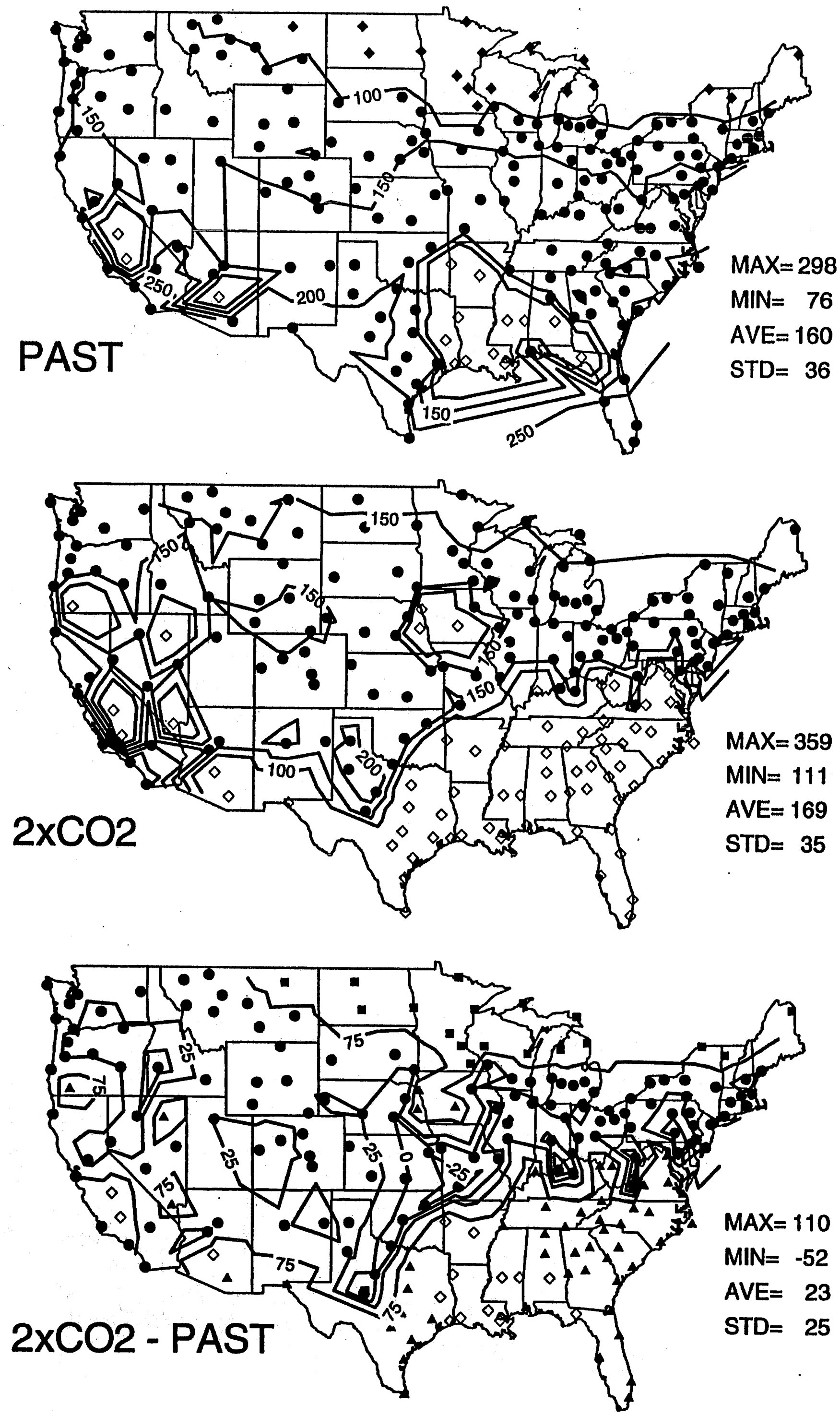

Fig. 28b Simulated **good-growth period (days)** of **cool-water fish in** *eutrophic, shallow, small lakes (Type 1, A_s=0.2 km^2)* under past (1962-1979)(top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

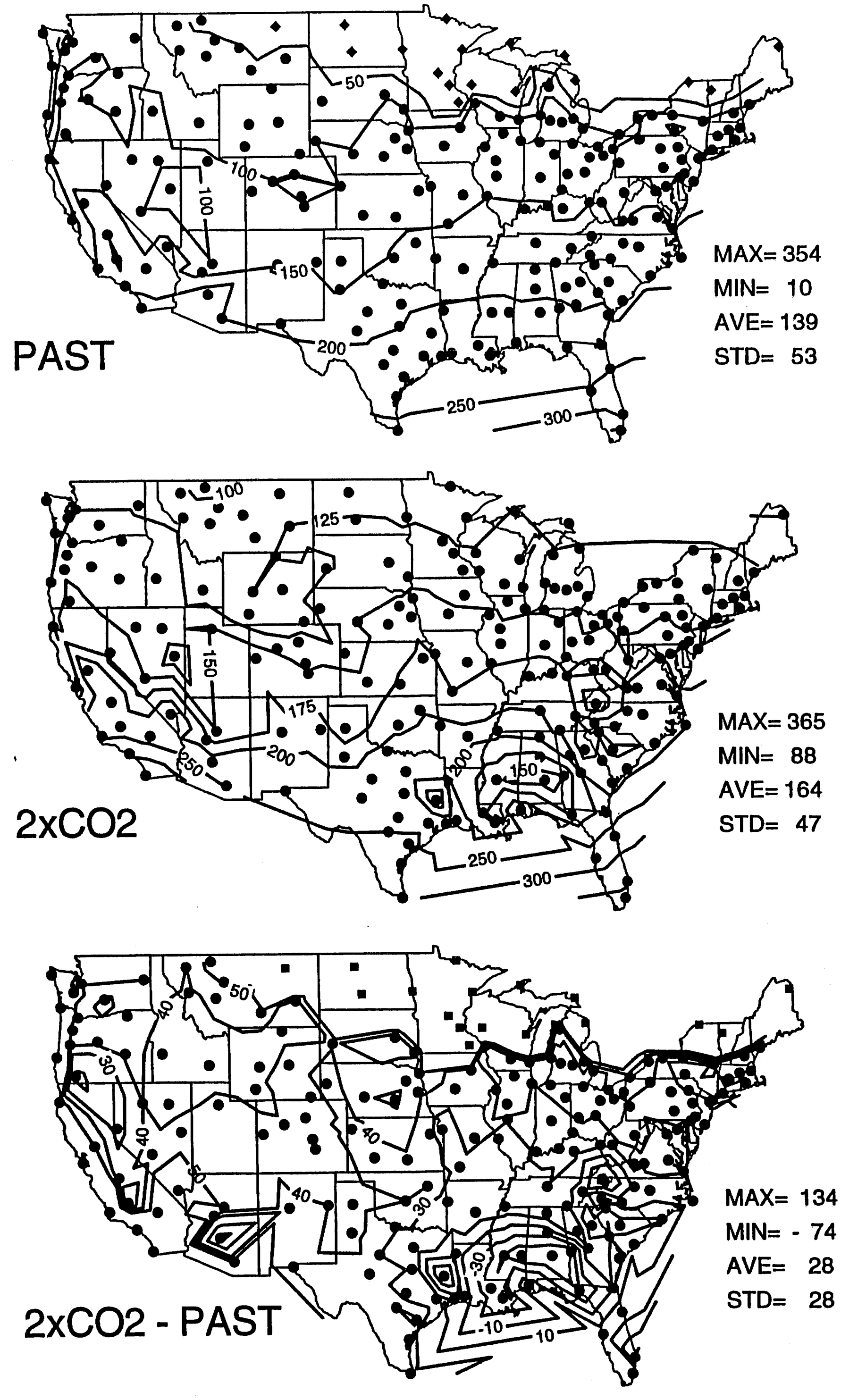

Fig. 28c Simulated **good-growth period (days)** of **warmwater fish in** *eutrophic, shallow, small lakes (Type 1, A_s=0.2 km²)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

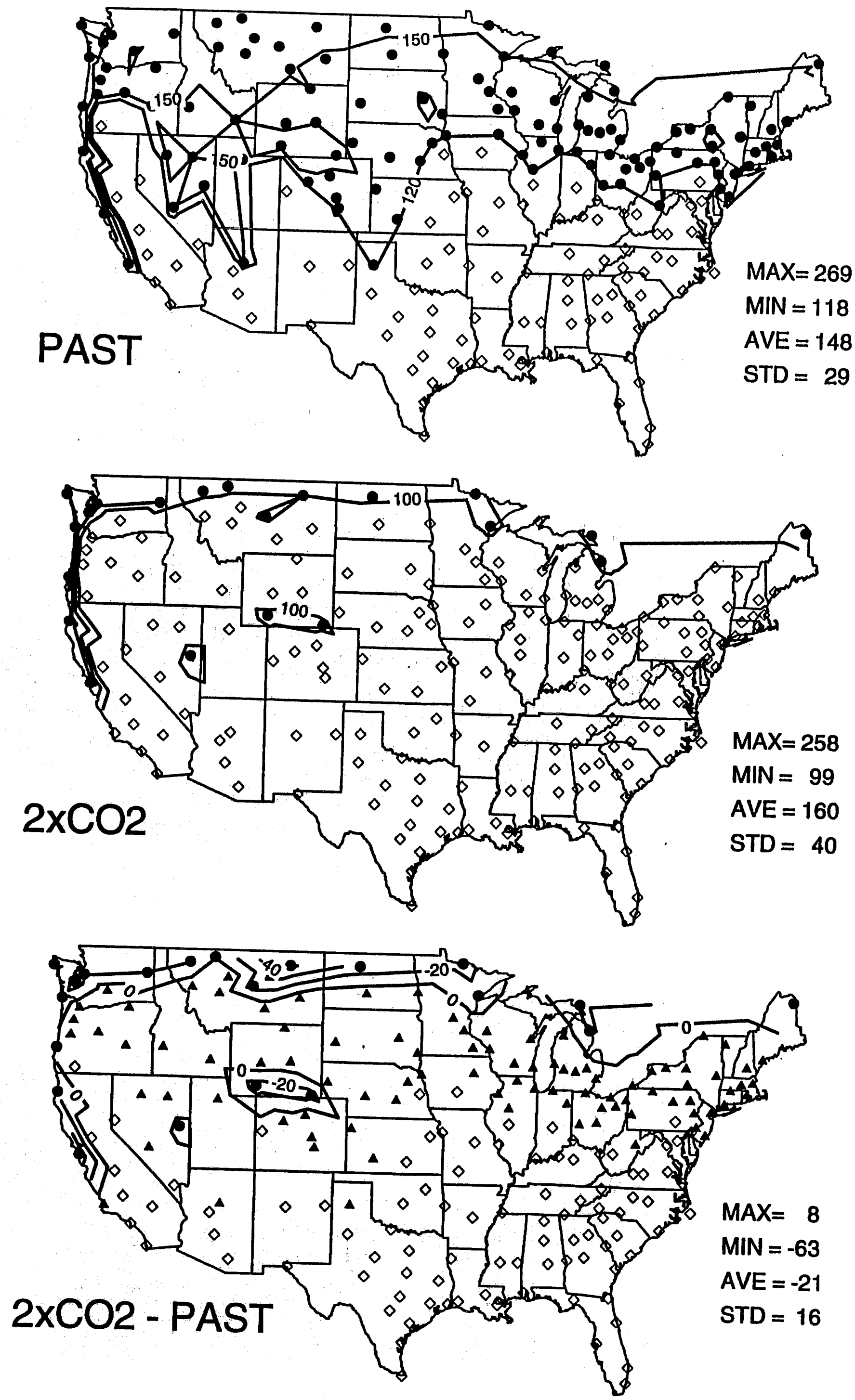

Fig. 29a Simulated **good-growth period (days)** of **cold-water fish in** *oligotrophic, medium-depth and -size lakes (Type 15, A_s=1.7km²)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

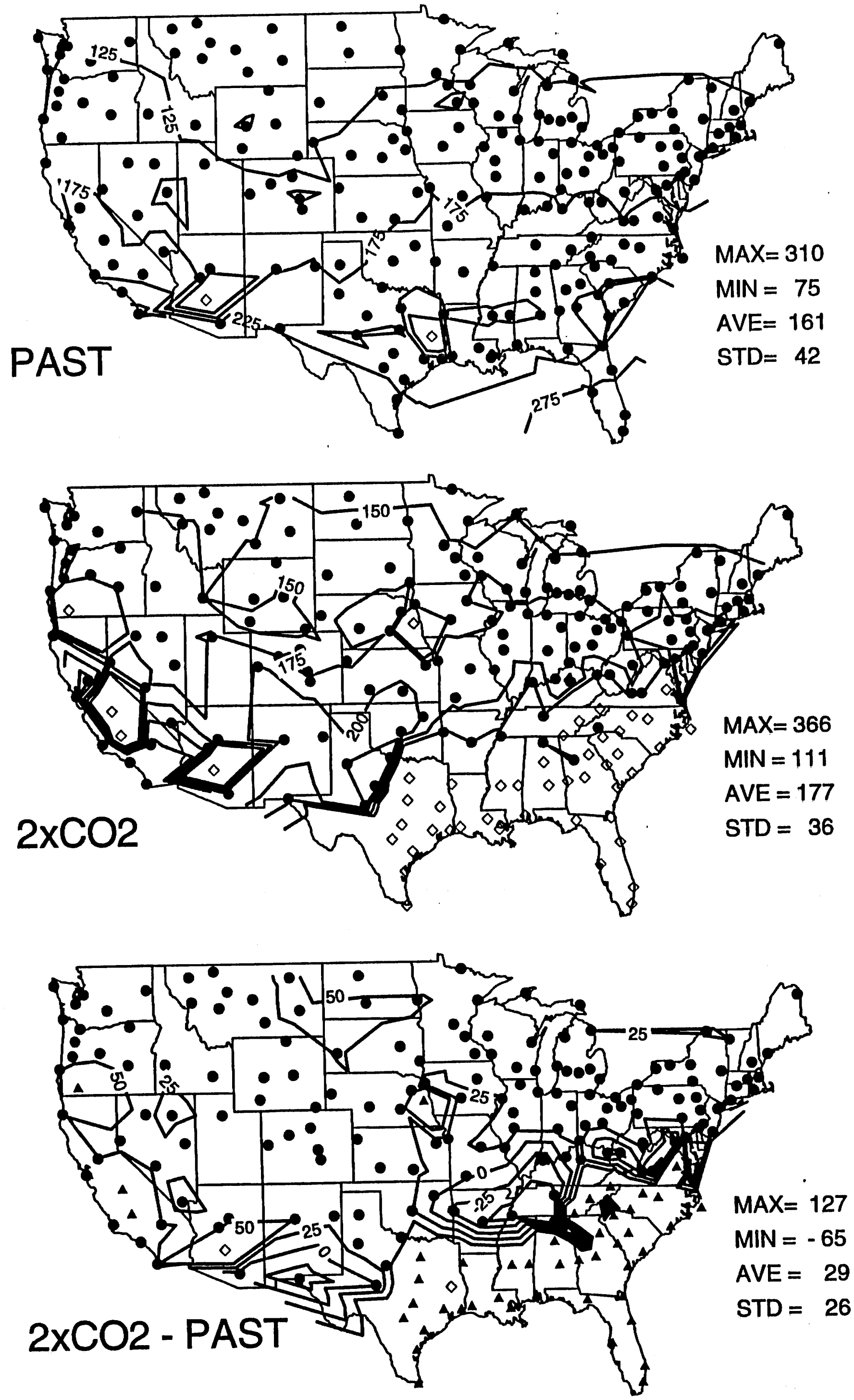

Fig. 29b Simulated **good-growth period (days)** of **cool-water fish in** *oligotrophic, medium-depth and -size lakes (Type 15, A_s=1.7km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

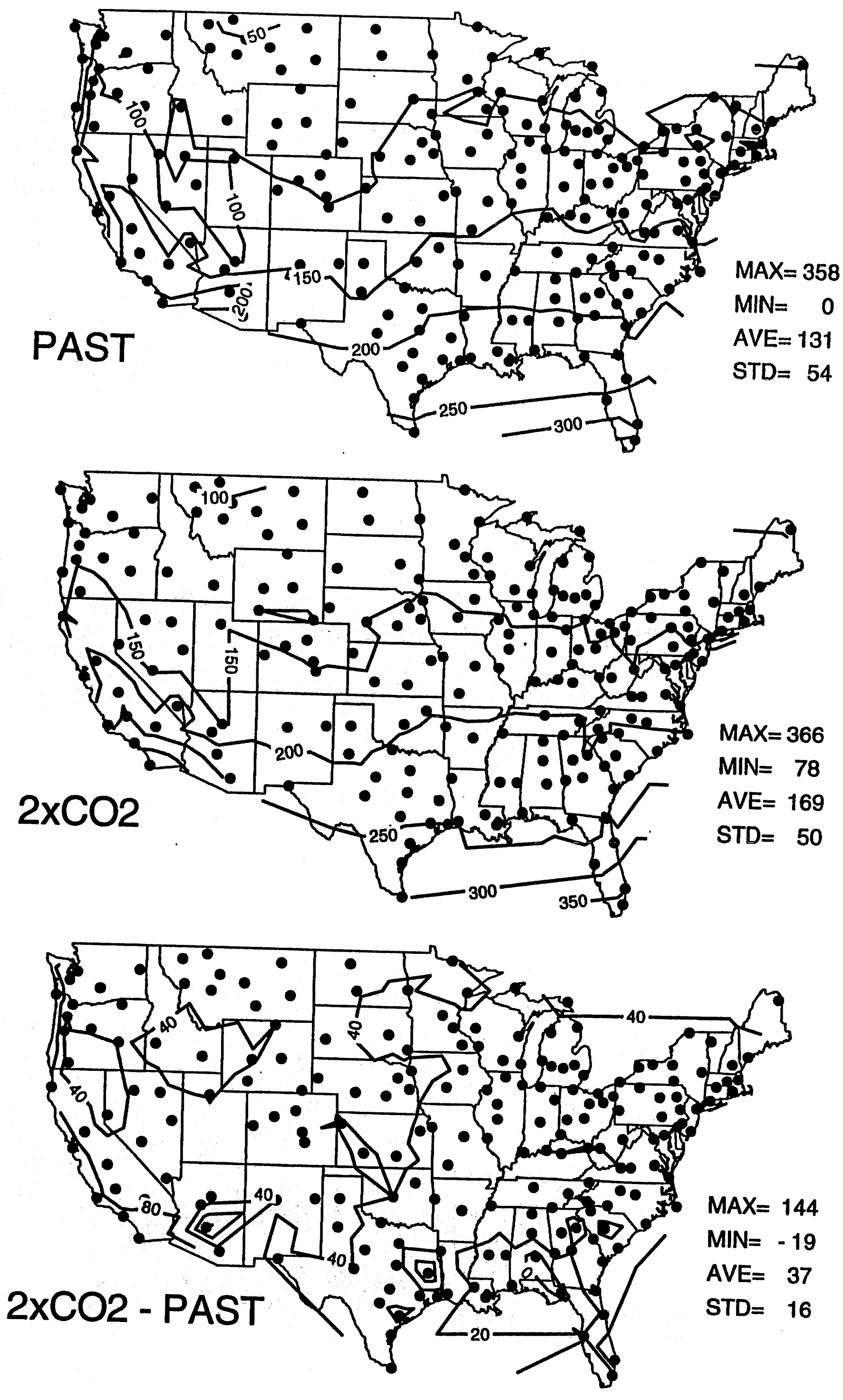

Fig. 29c Simulated **good-growth period (days)** of **warmwater fish in** *oligotrophic, medium-depth and -size lakes (Type 15, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

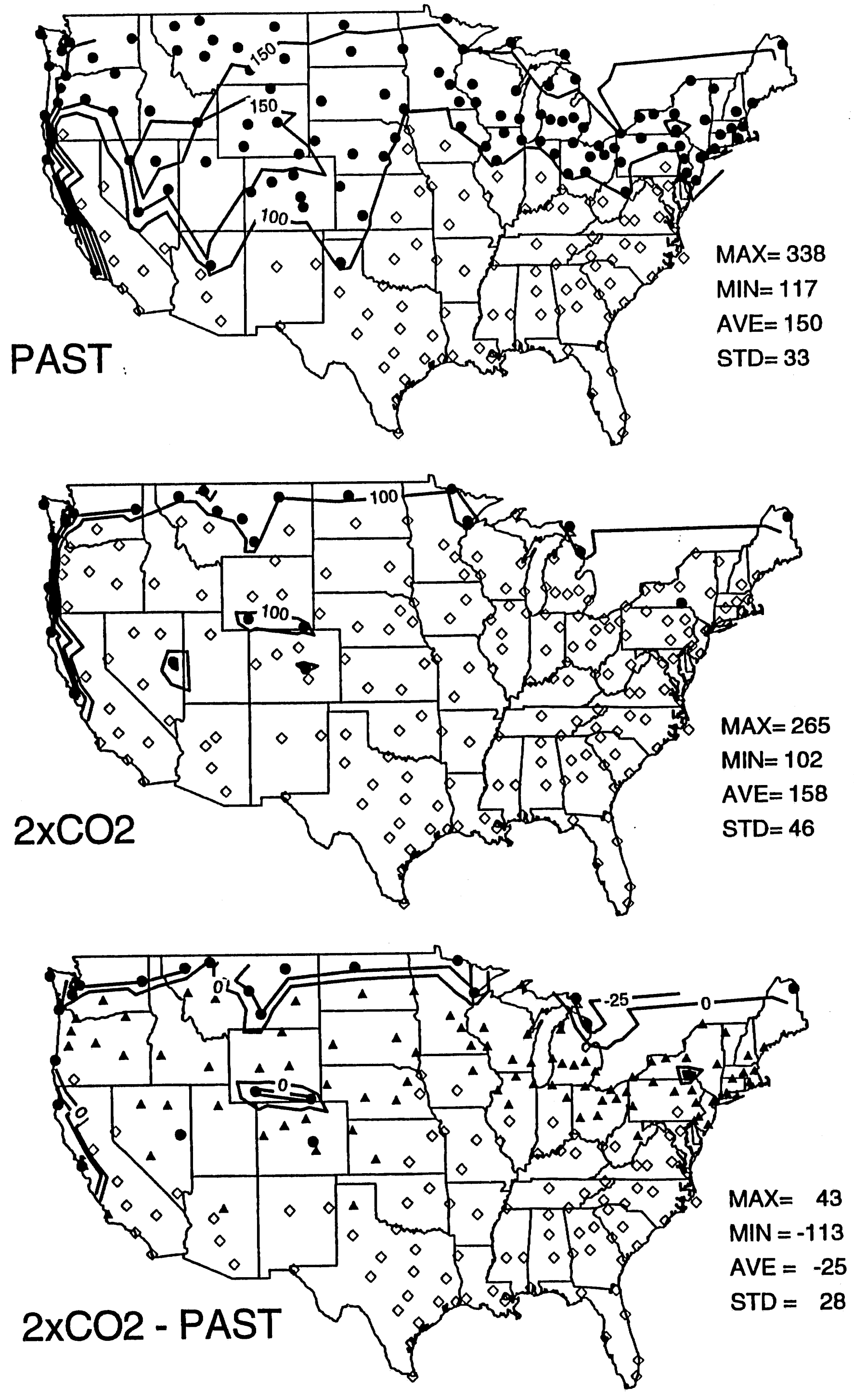

Fig. 30a Simulated **good-growth period (days)** of **cold-water fish in** *eutrophic, medium-depth and -size lakes (Type 13,* A_s*=1.7km*^{2}*)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

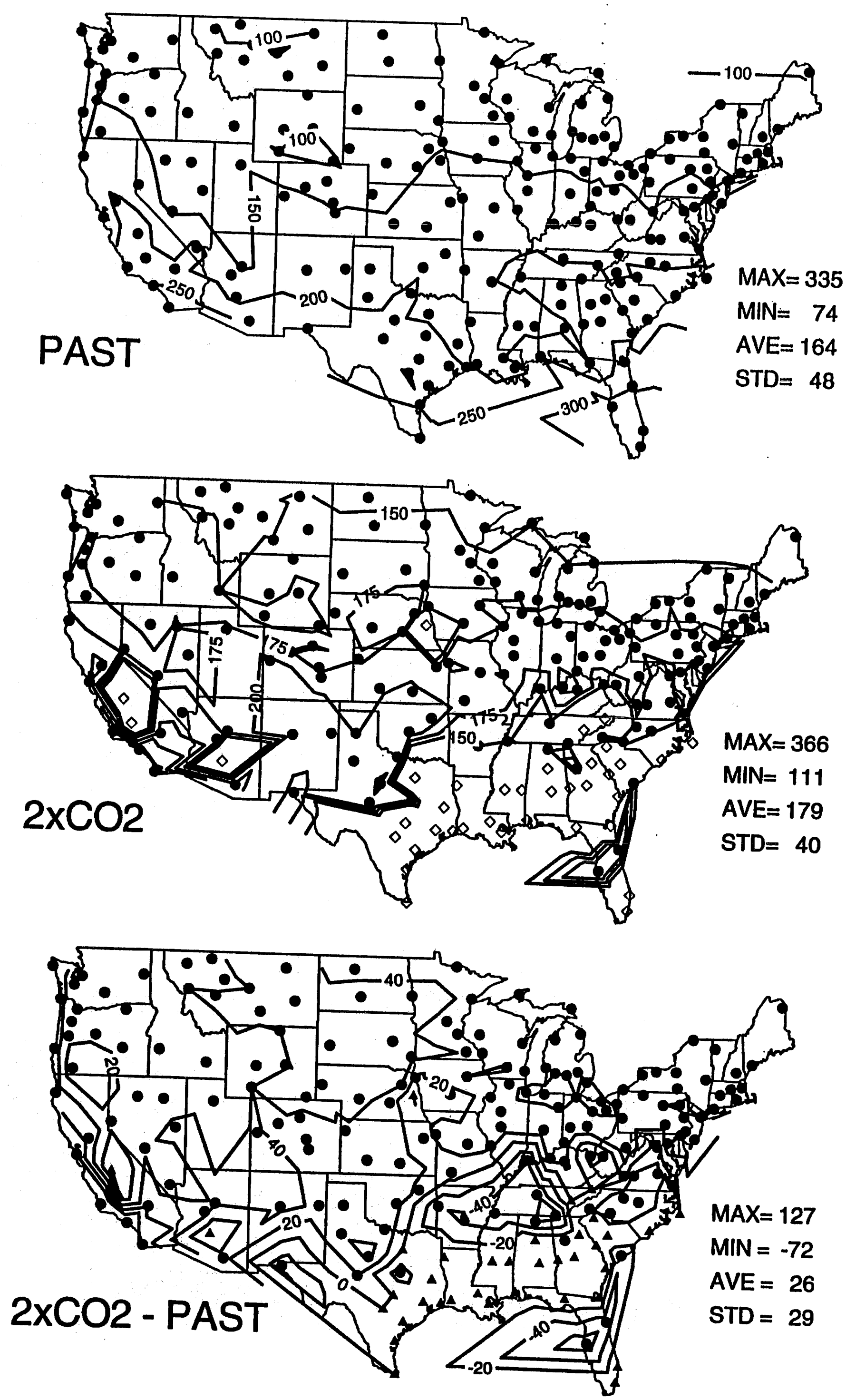

Fig. 30b Simulated **good-growth period (days)** of **cool-water fish in** *eutrophic, medium-depth and -size lakes (Type 13, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

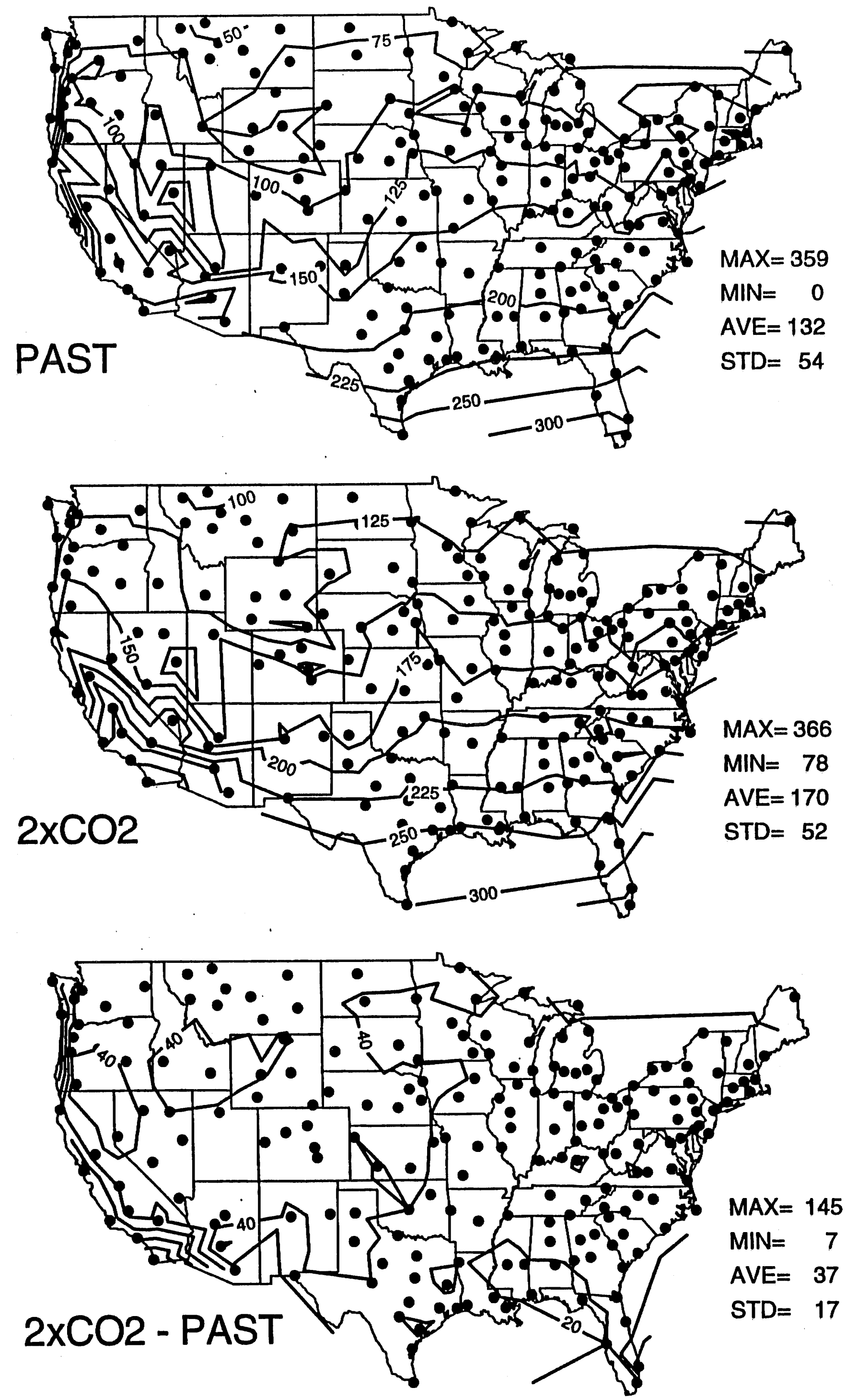

Fig. 30c Simulated **good-growth period (days)** of **warmwater fish in** *eutrophic, medium-depth and -size lakes (Type 13, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

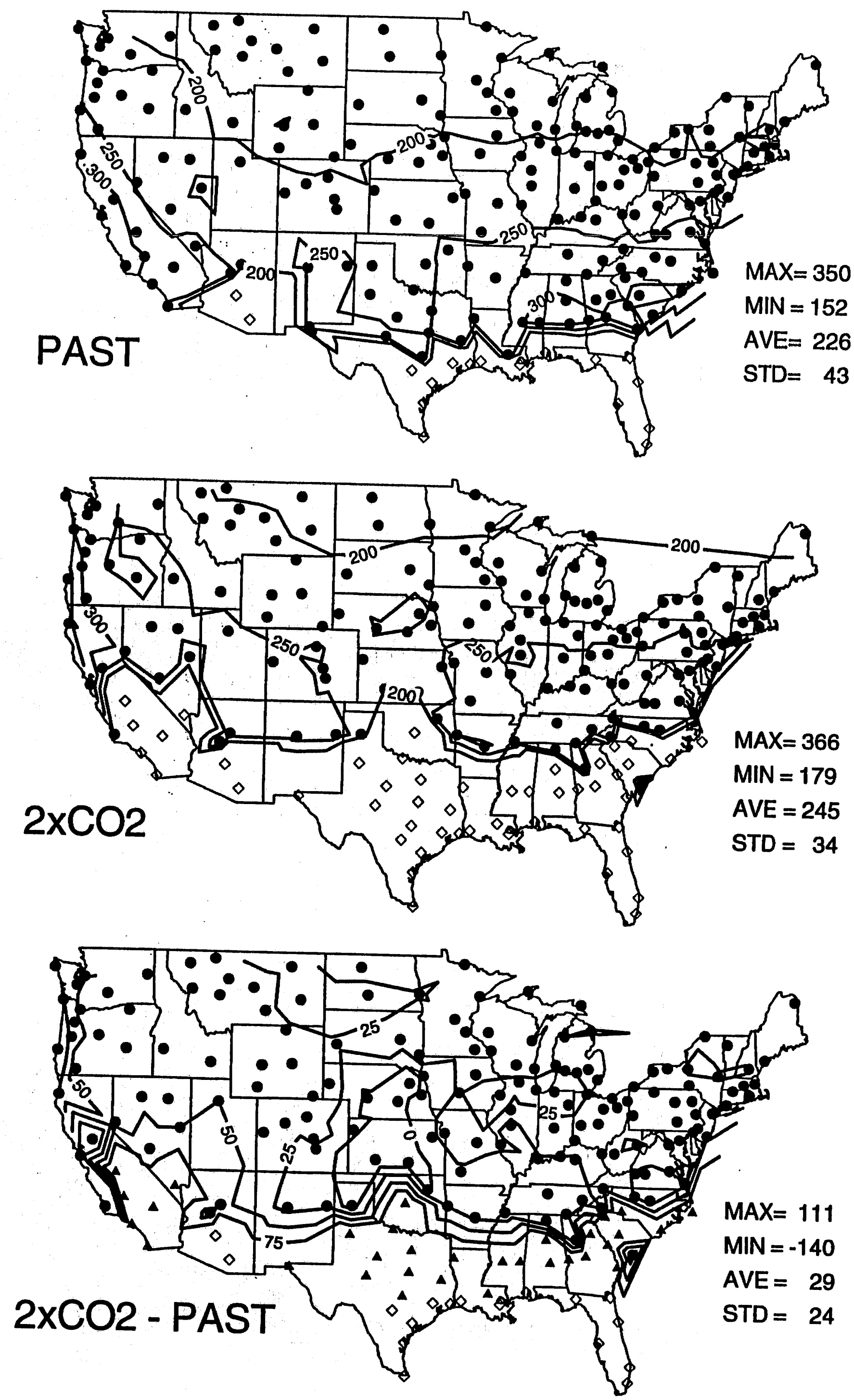

Fig. 31a Simulated **good-growth period (days)** of **cold-water fish in** *oligotrophic, deep, medium-size lakes (Type 24, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

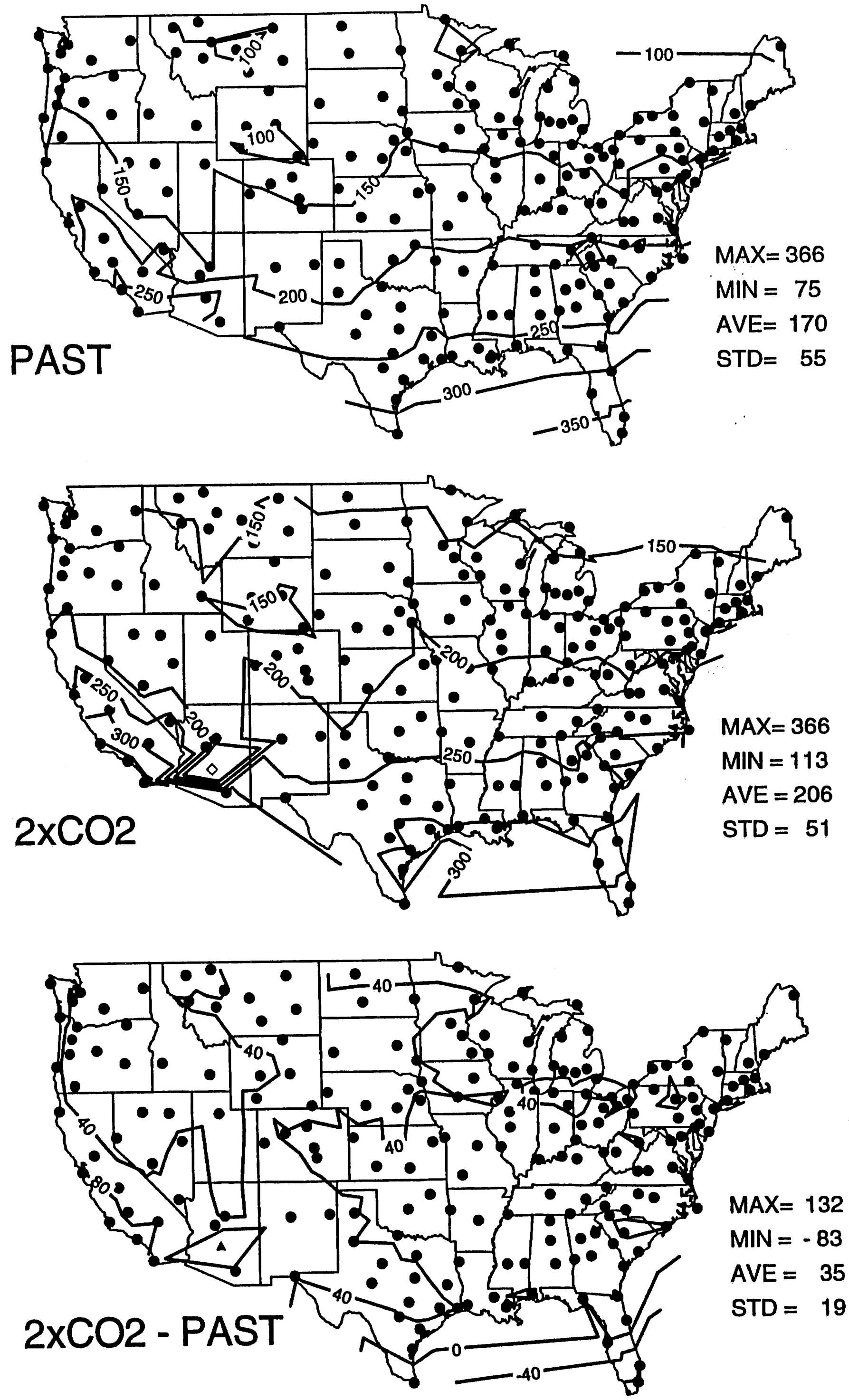

Fig. 31b Simulated **good-growth period (days)** of **cool-water fish in** *oligotrophic, deep, medium-size lakes (Type 24, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

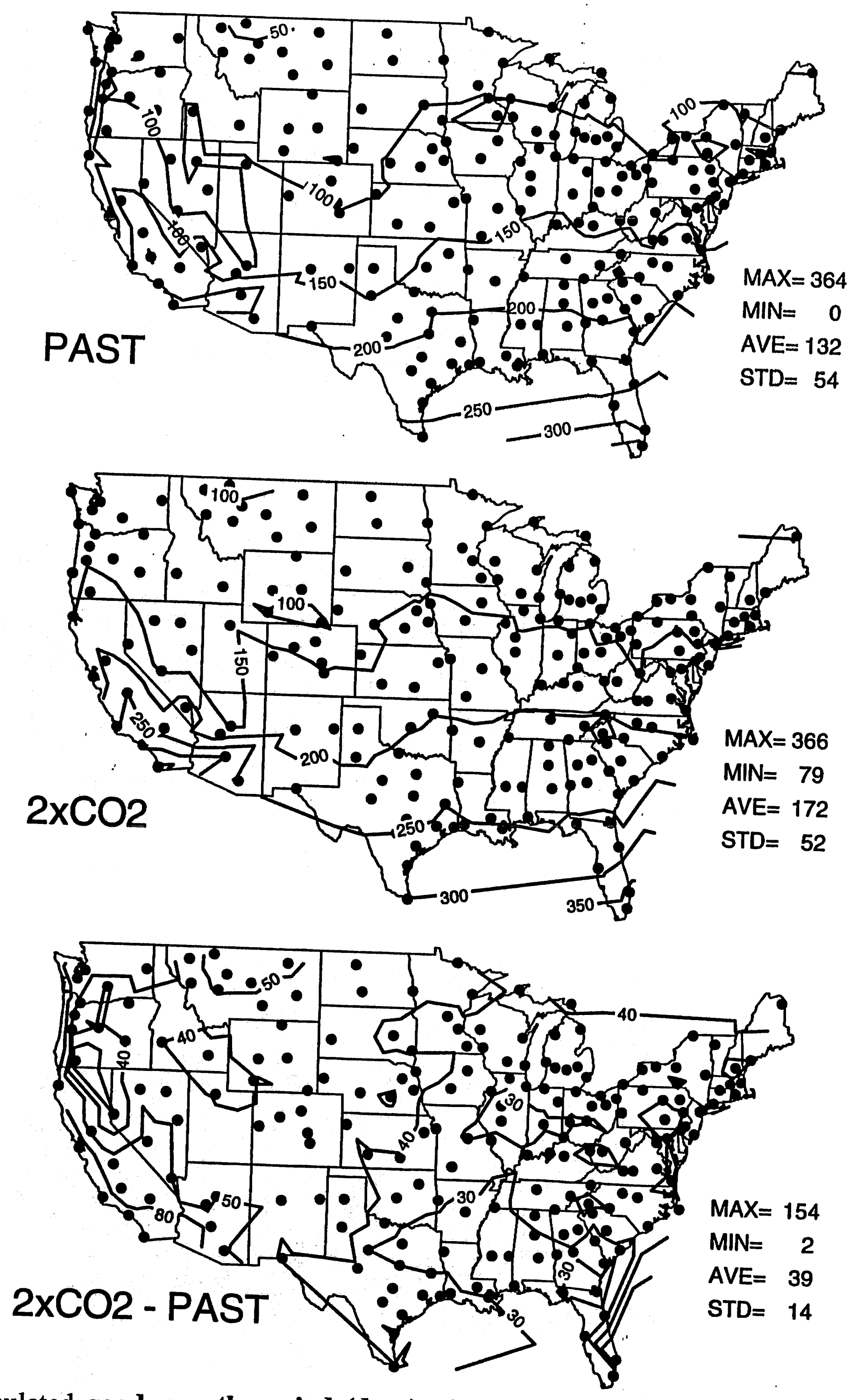

Fig. 31c Simulated **good-growth period (days)** of **warmwater fish in** *oligotrophic, deep, medium-size lakes (Type 24, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

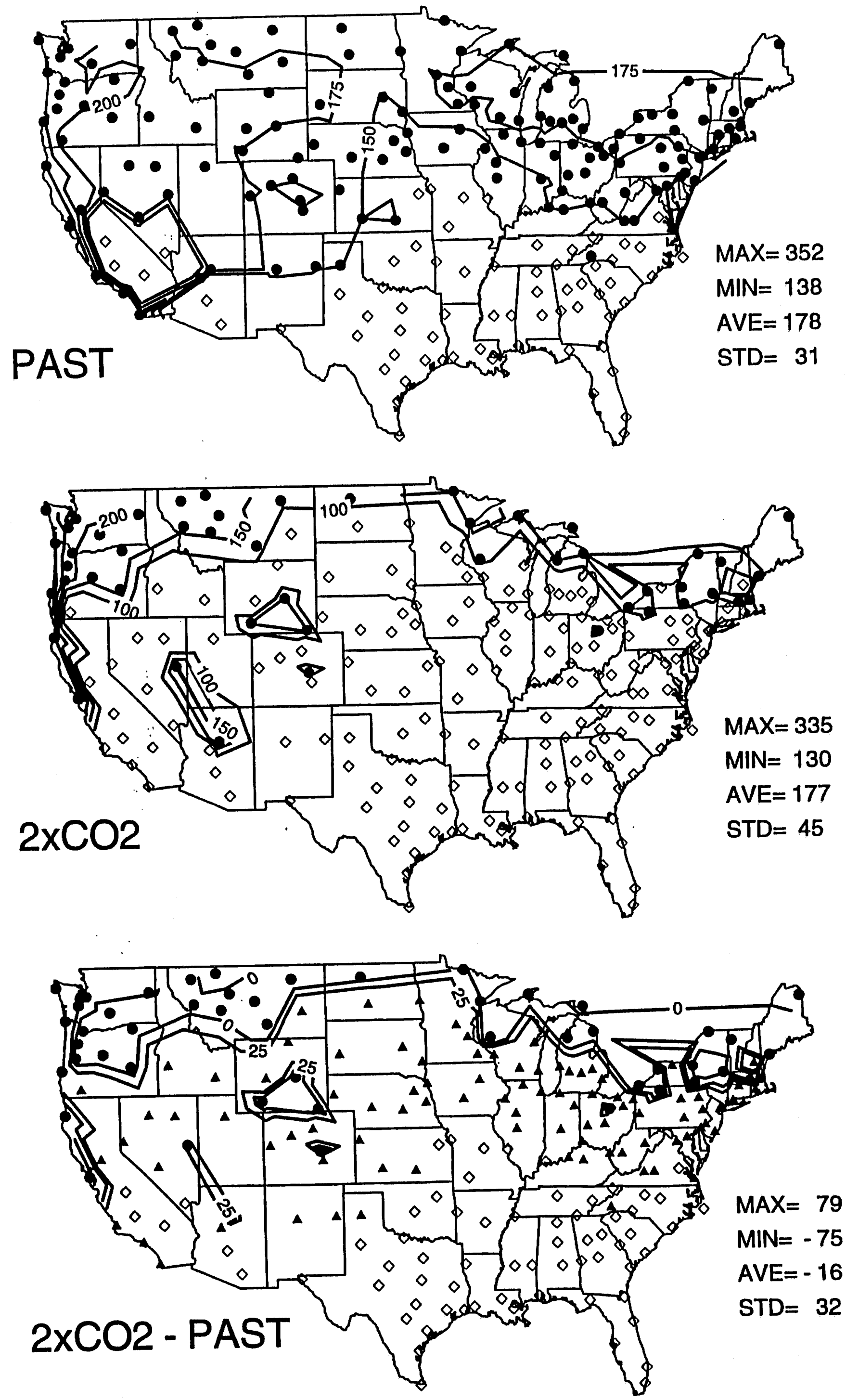

Fig. 32a Simulated **good-growth period (days)** of **cold-water fish in** *eutrophic, deep, medium-size lakes (Type 22, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

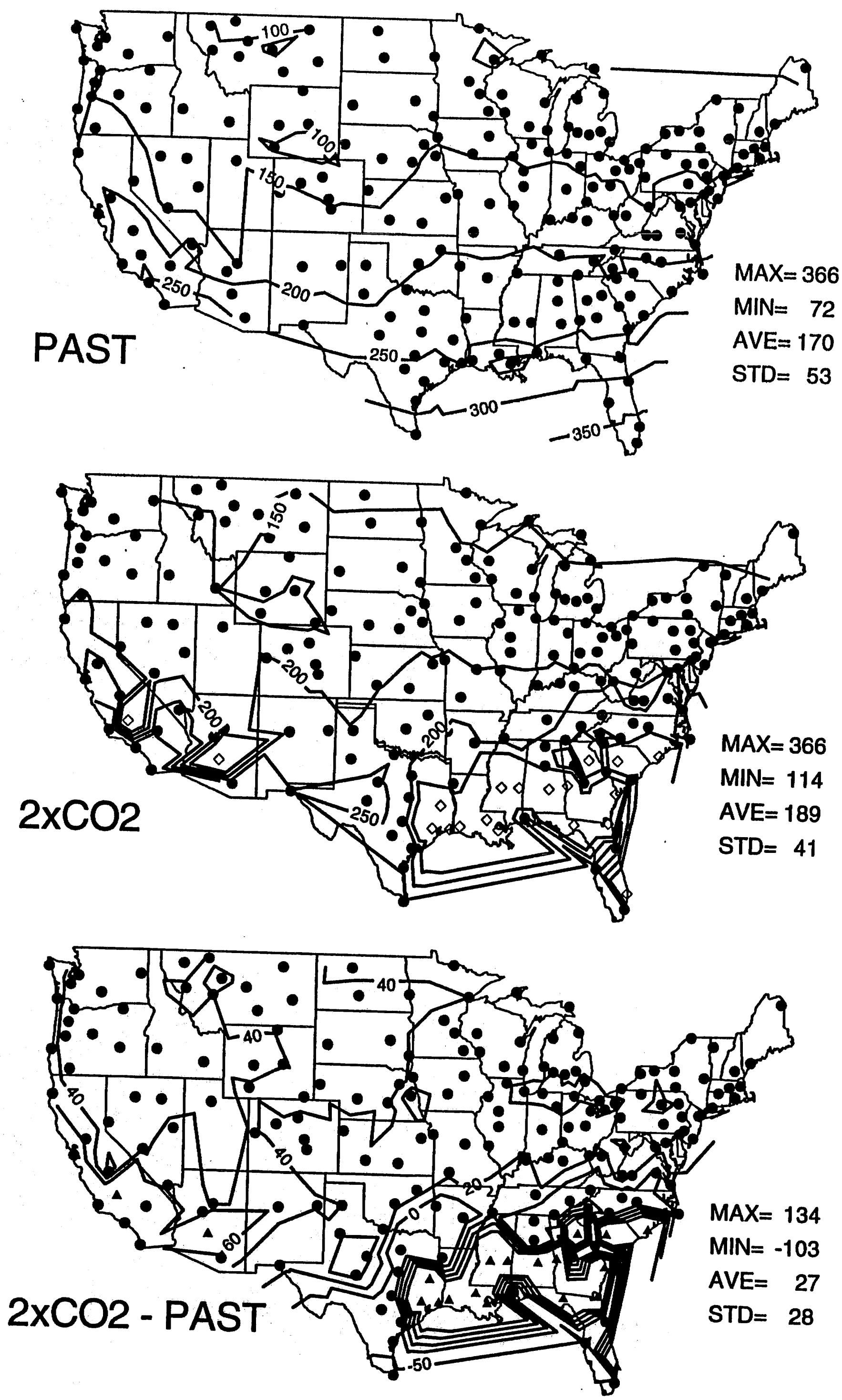

Fig. 32b Simulated **good-growth period (days)** of **cool-water fish in** *eutrophic, deep, medium-size lakes (Type 22, $A_s=1.7km^2$)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

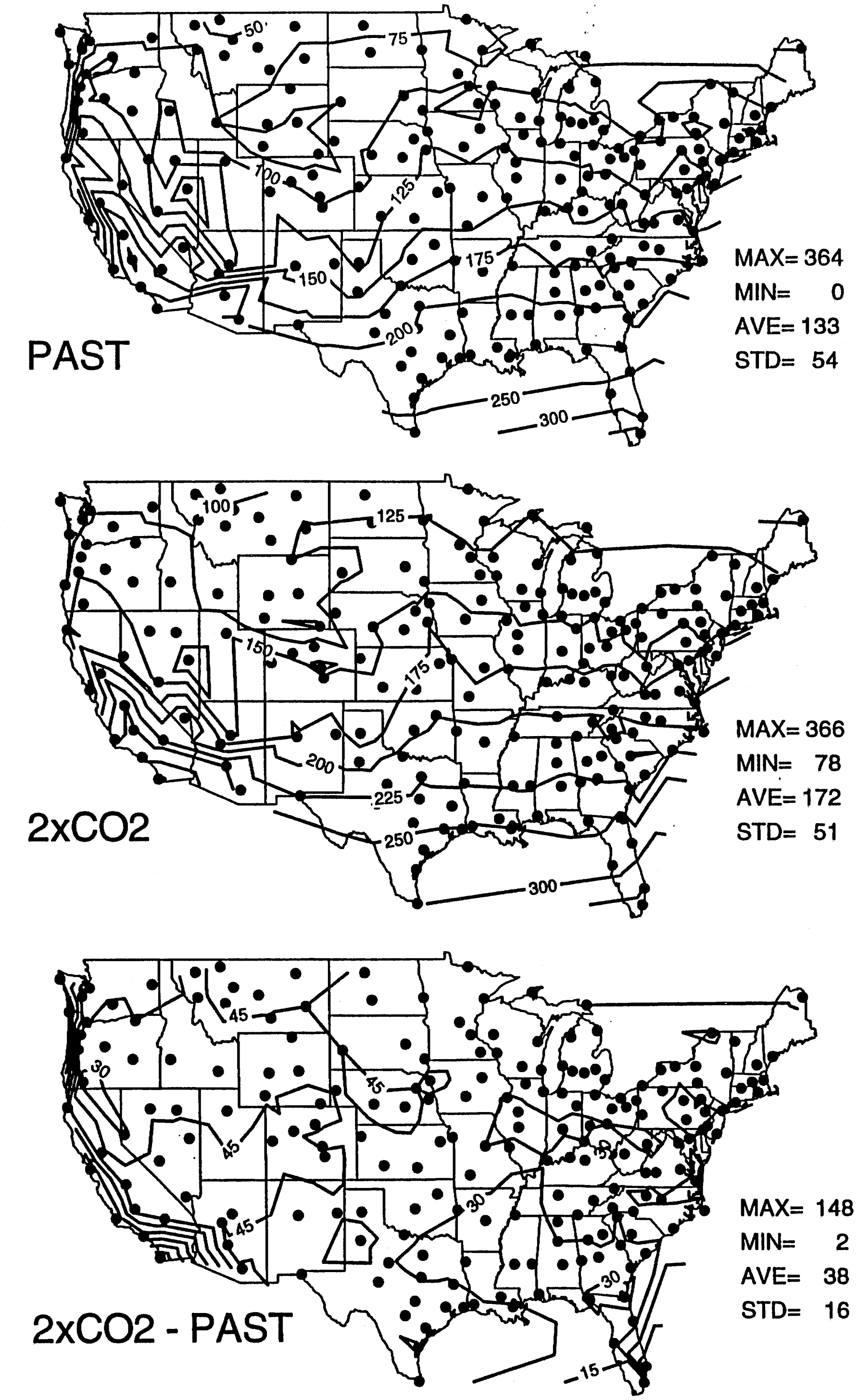

Fig. 32c Simulated **good-growth period (days)** of **warmwater fish in** *eutrophic, deep, medium-size lakes (Type 22, A_s=1.7km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

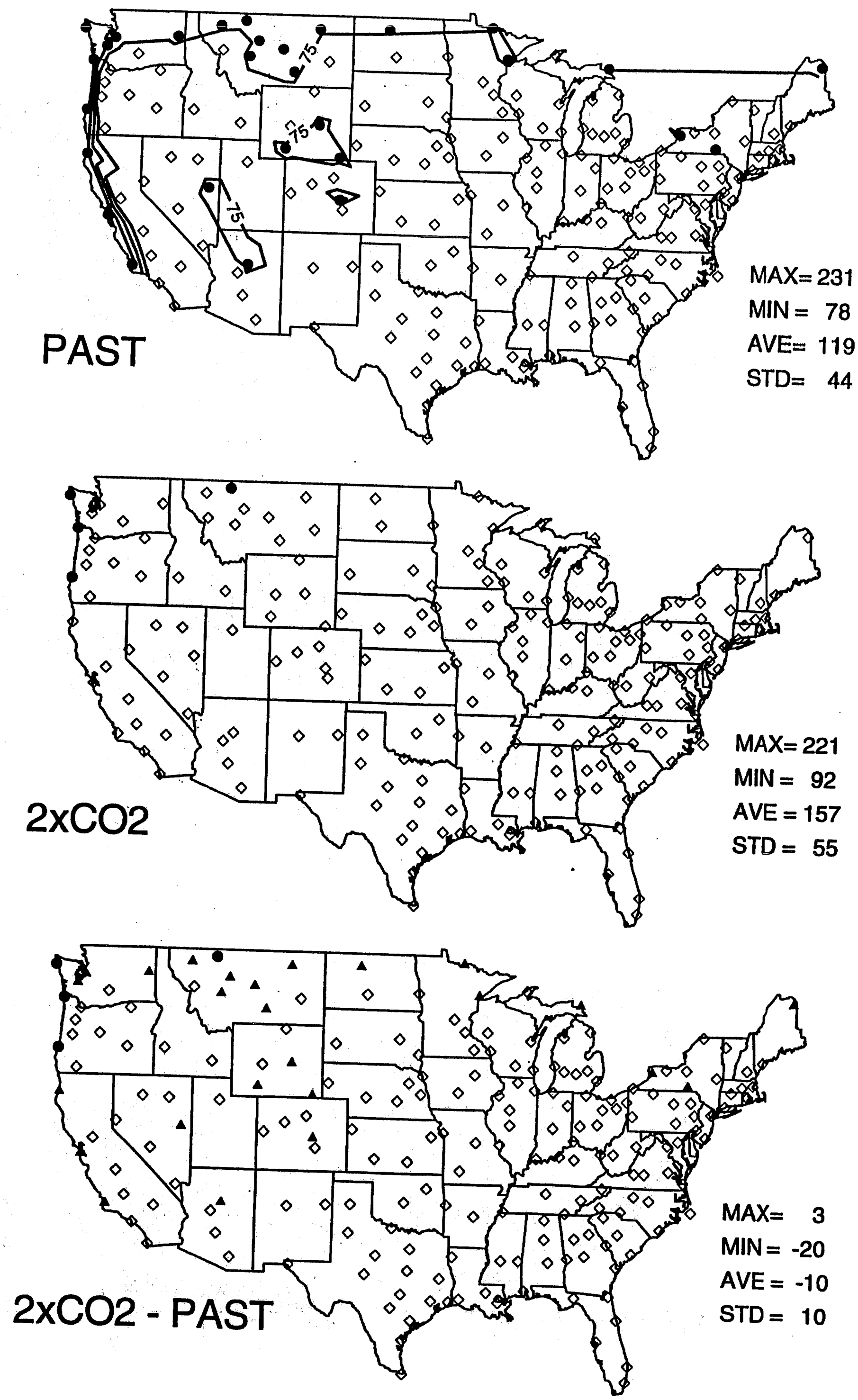

Fig. 33a Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cold-water fish** for *oligotrophic, shallow, large lakes (Type 9, A_s=10 km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

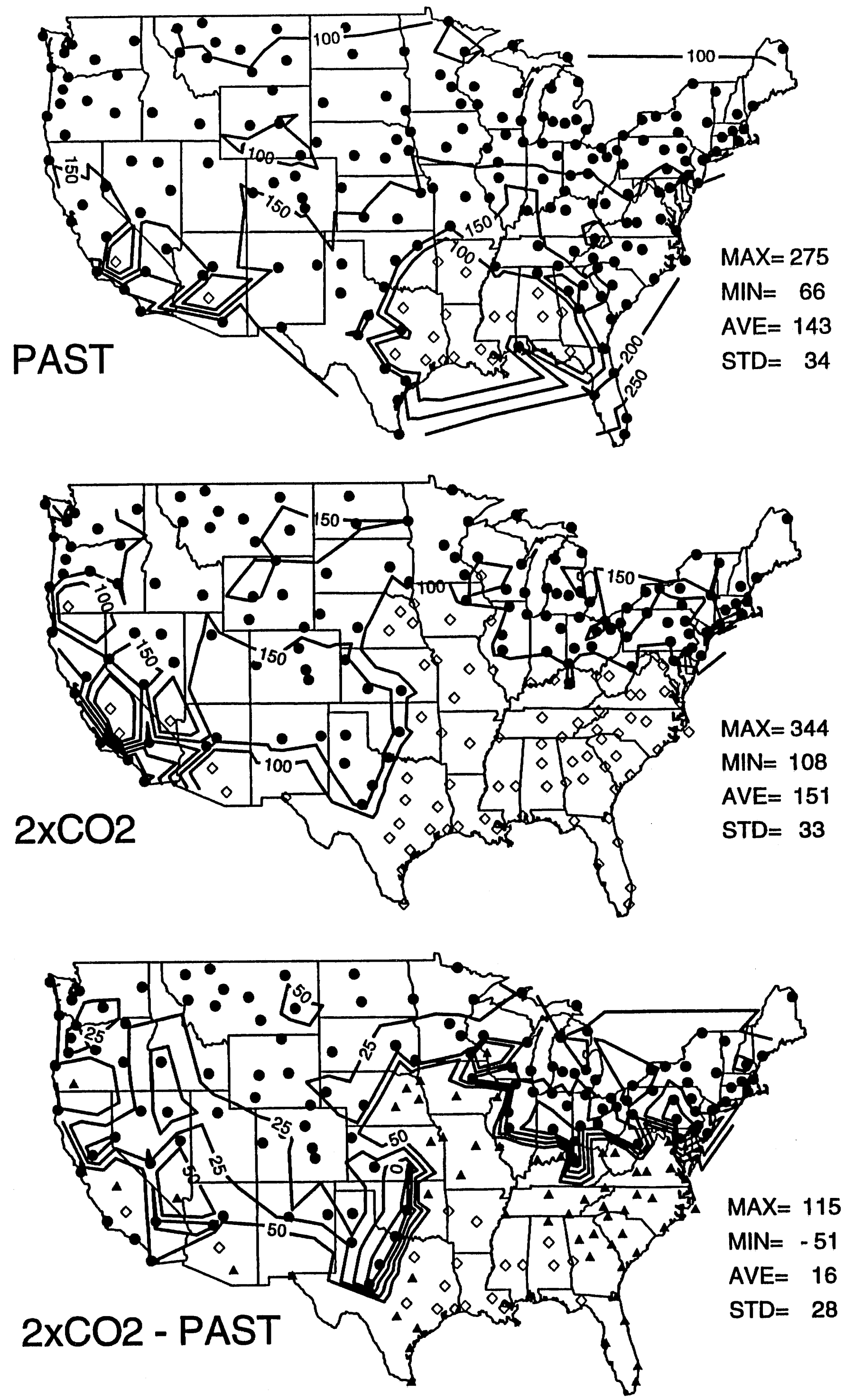

Fig. 33b Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cool-water fish** for *oligotrophic, shallow, large lakes (Type 9,* A_s*=10* km^2*)* under past (1962-1979)(top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

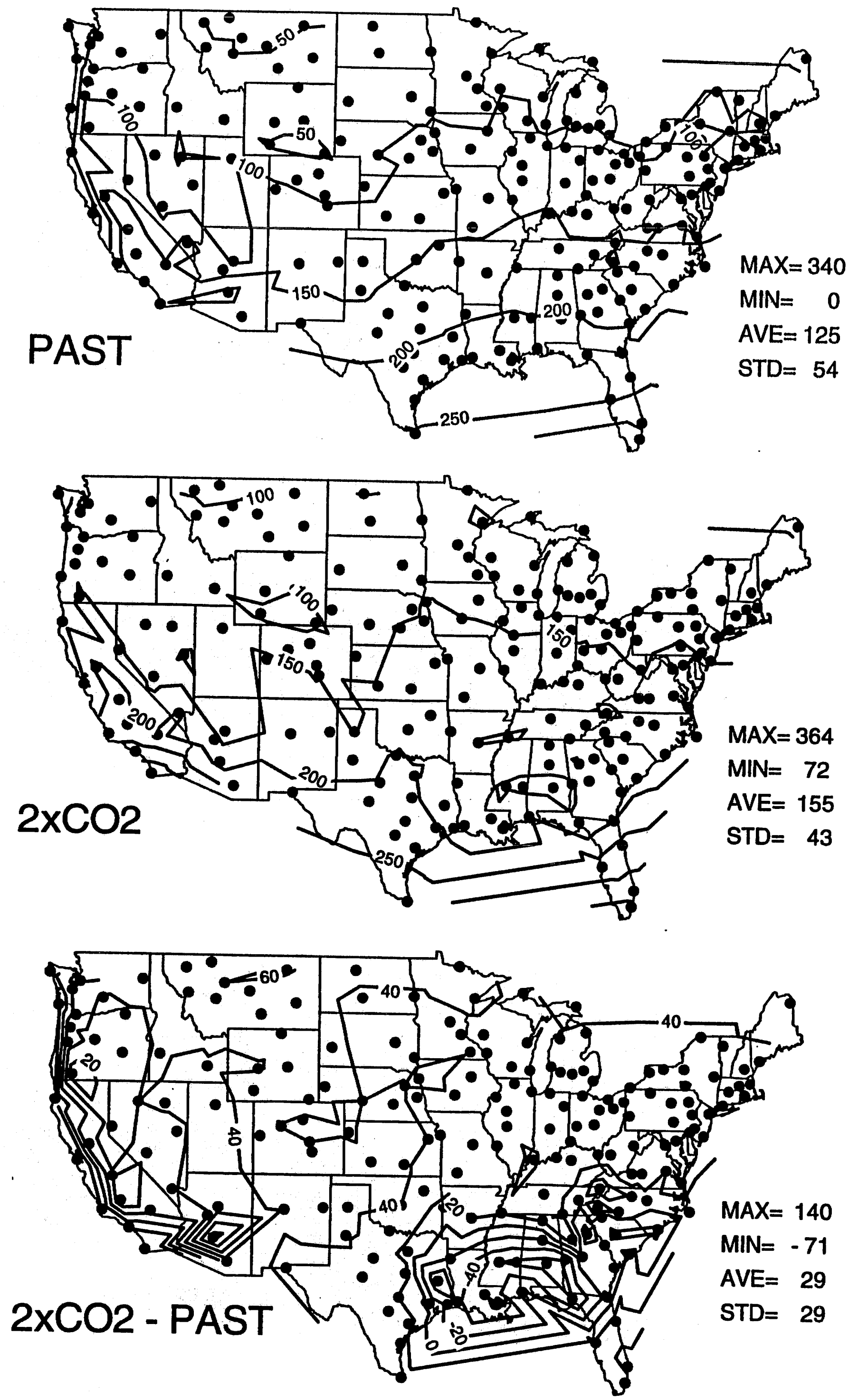

Fig. 33c Simulated, time integrated and **normalized good-growth habitat areas (days)** of **warmwater fish** for *oligotrophic, shallow, large lakes (Type 9, A_s=10km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

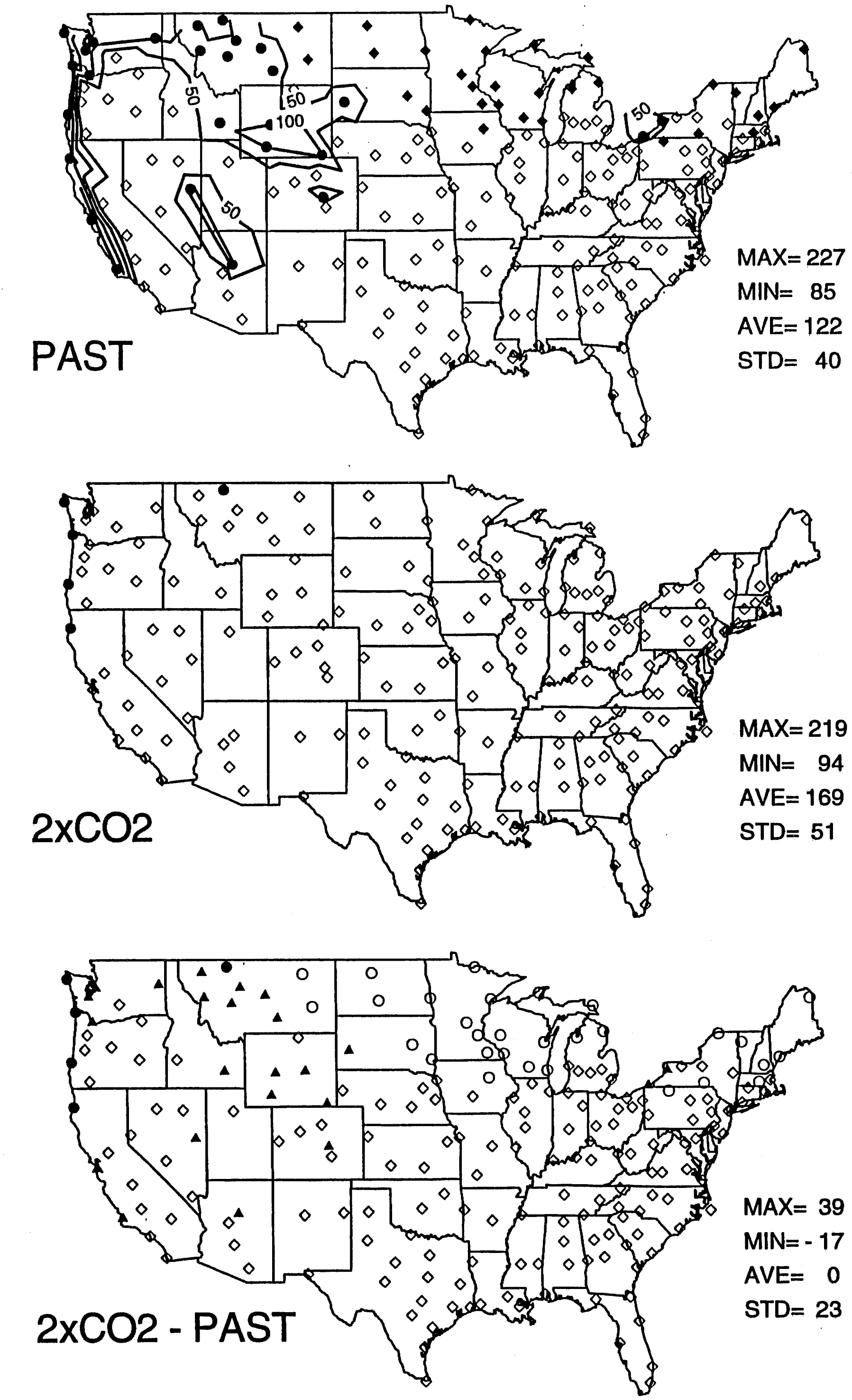

Fig. 34a Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cold-water fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10 km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

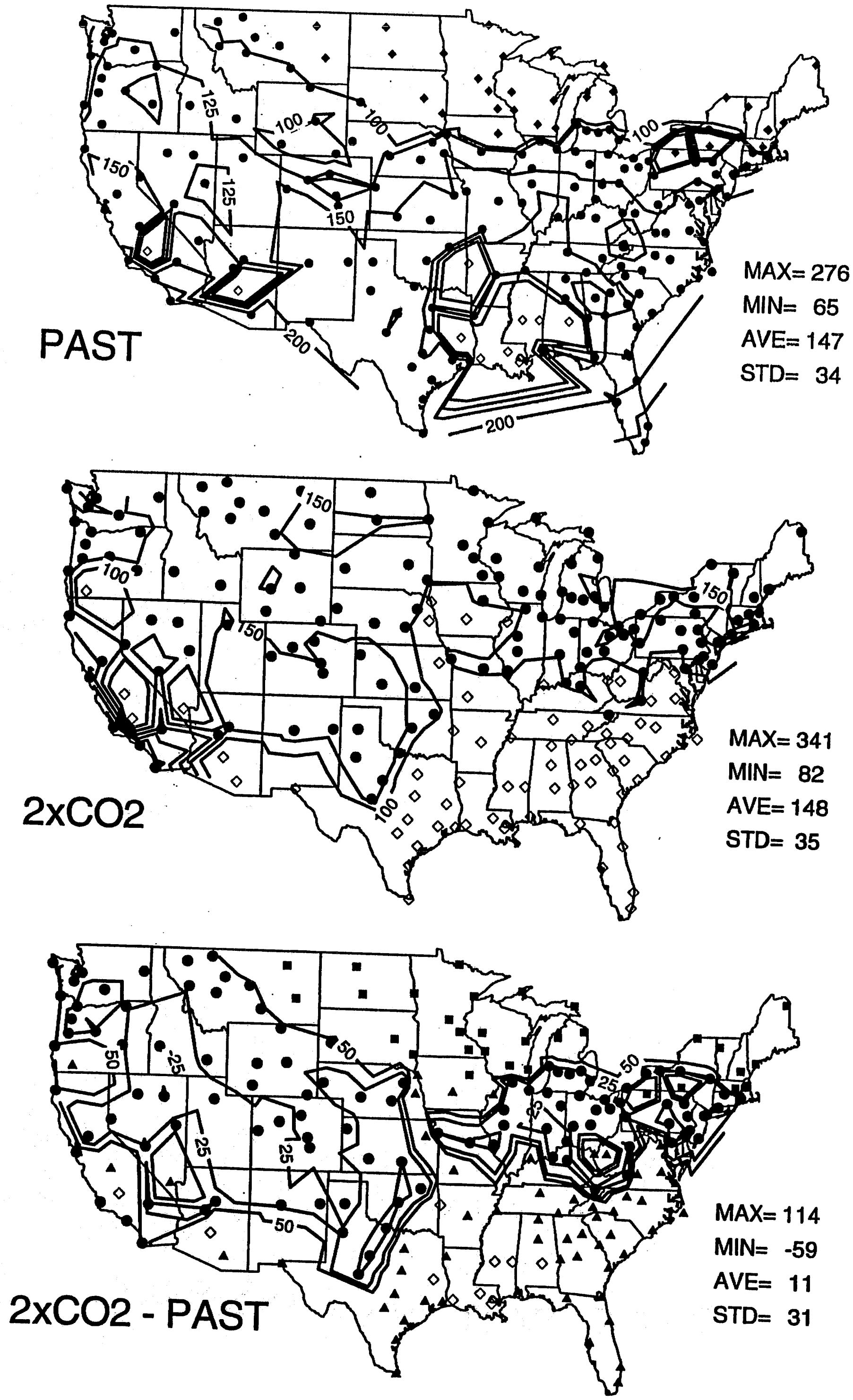

Fig. 34b Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cool-water fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10 km^2)* under past (1962-1979)(top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

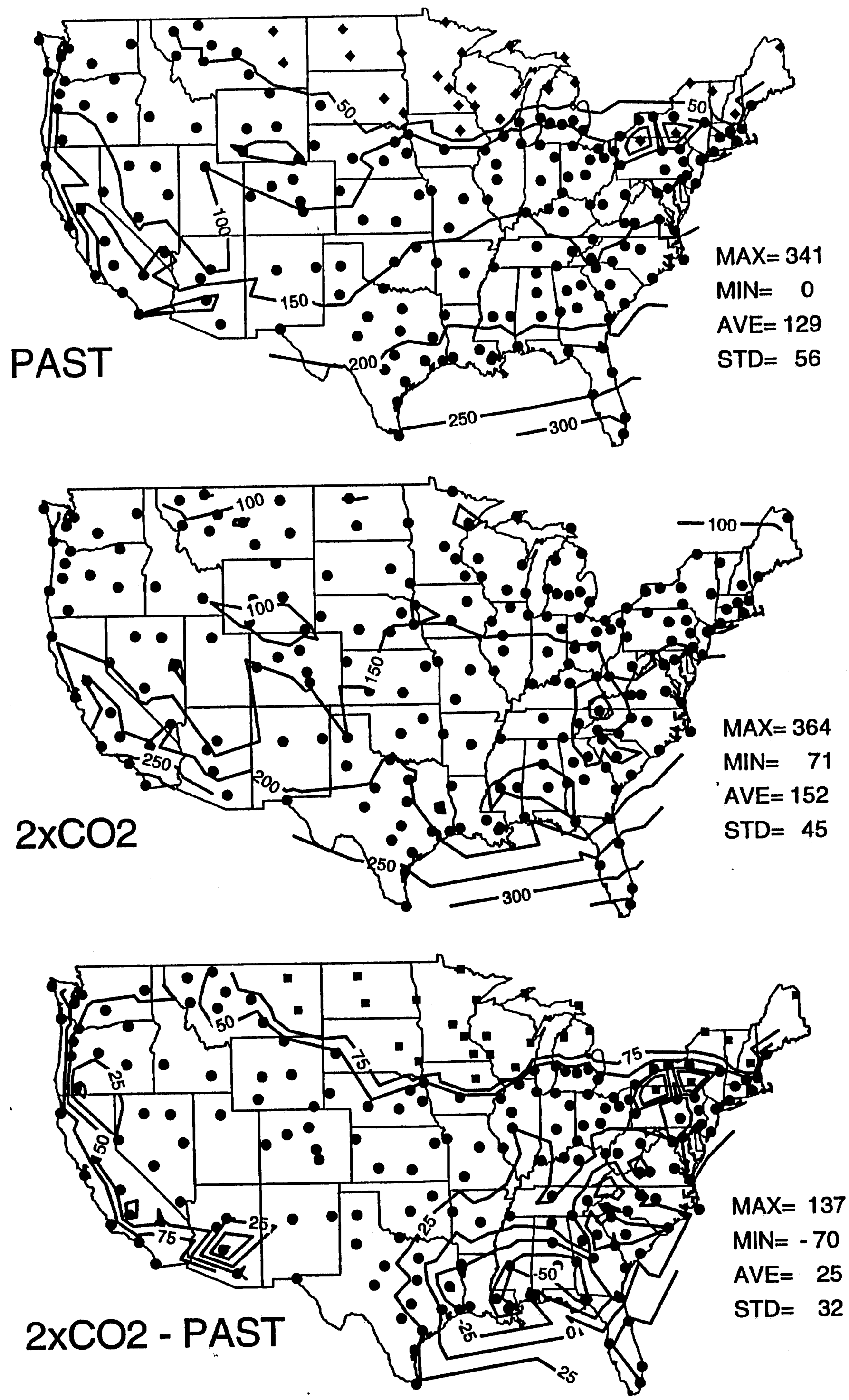

Fig. 34c Simulated, time integrated and **normalized good-growth habitat areas (days)** of **warmwater fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10km²)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

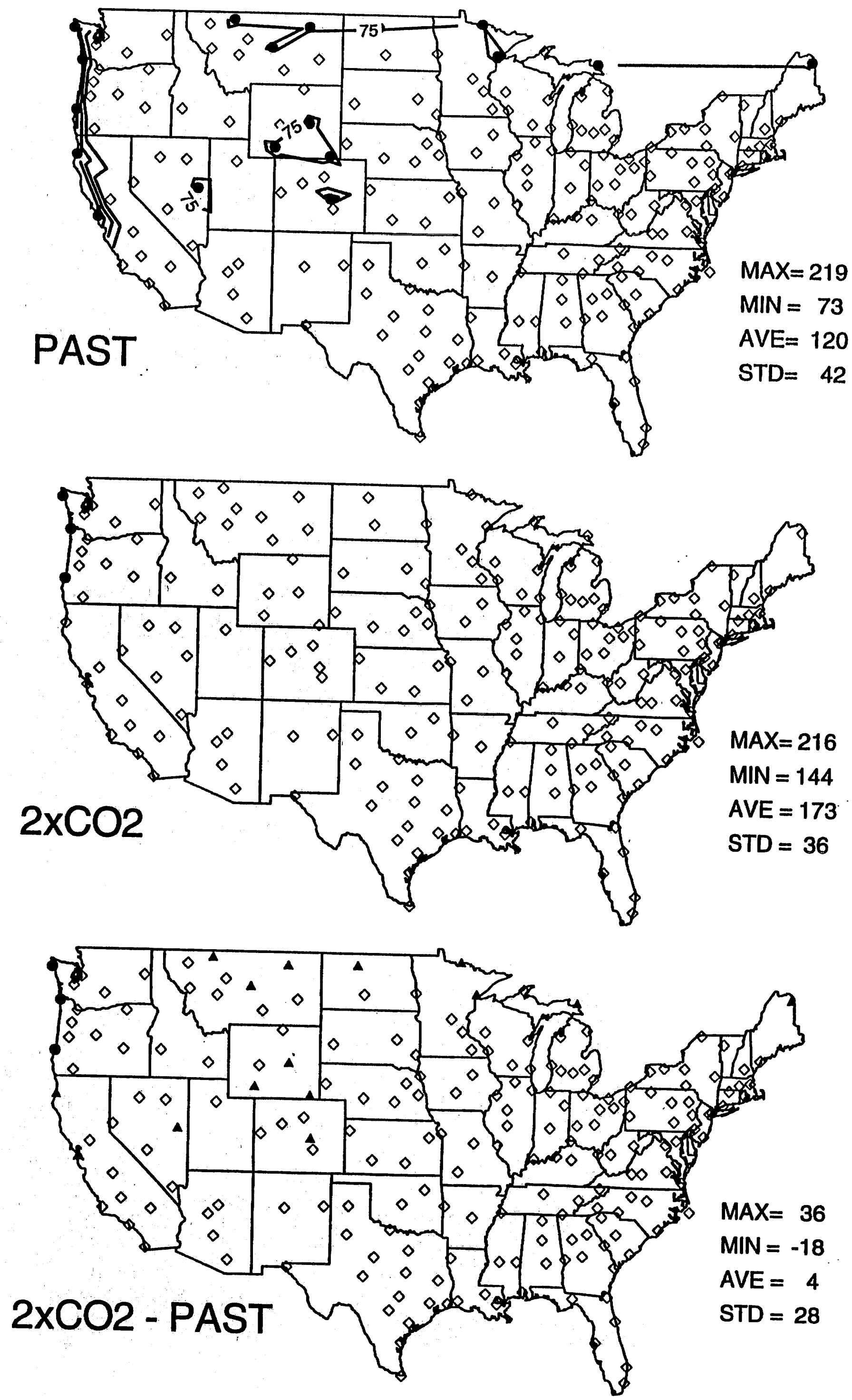

Fig. 35a Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cold-water fish in** *oligotrophic, shallow, small lakes (Type 3, A_s=0.2 km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

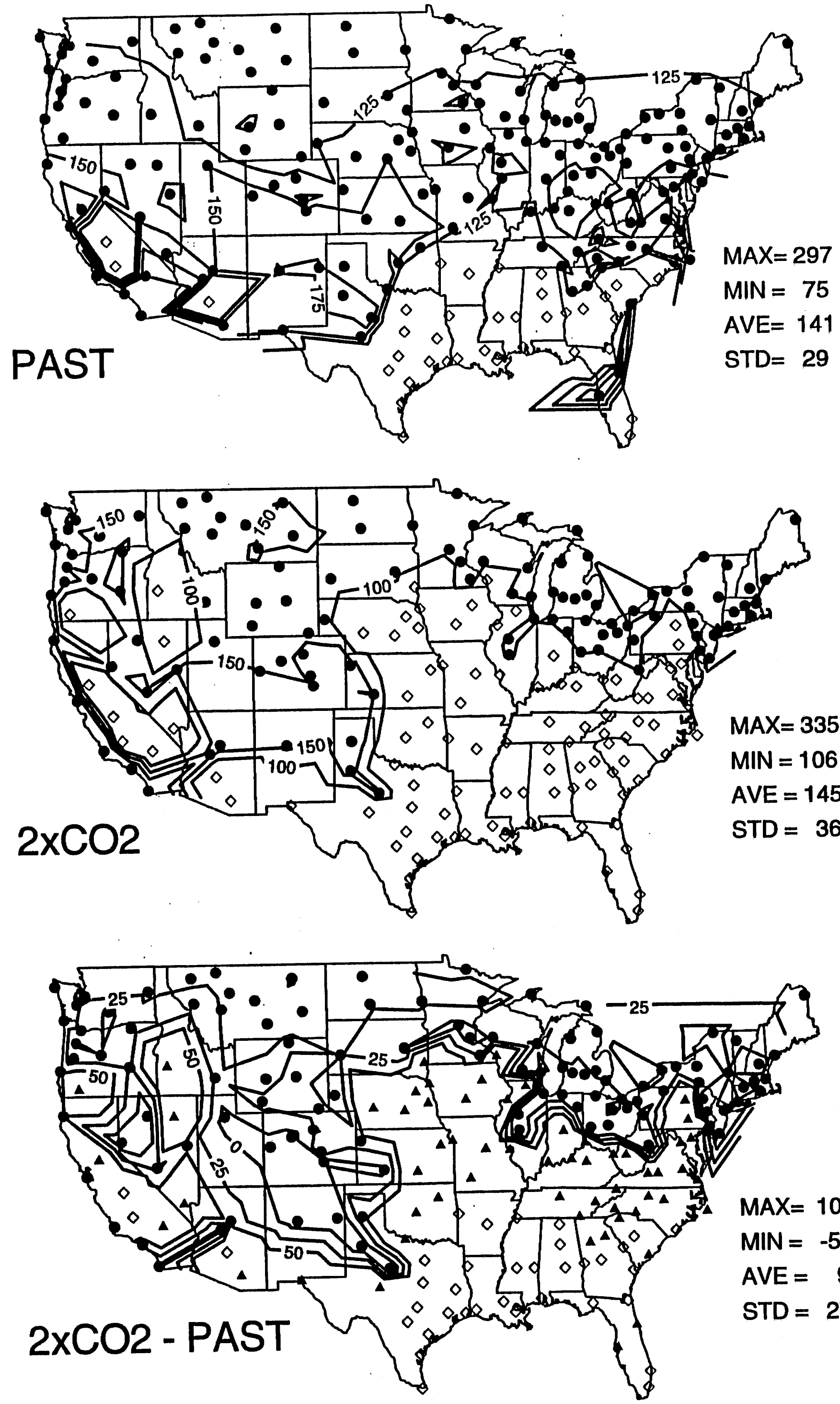

Fig. 35b Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cool-water fish in** *oligotrophic, shallow, small lakes (Type 3,* A_s*=0.2 km*^{2}*)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

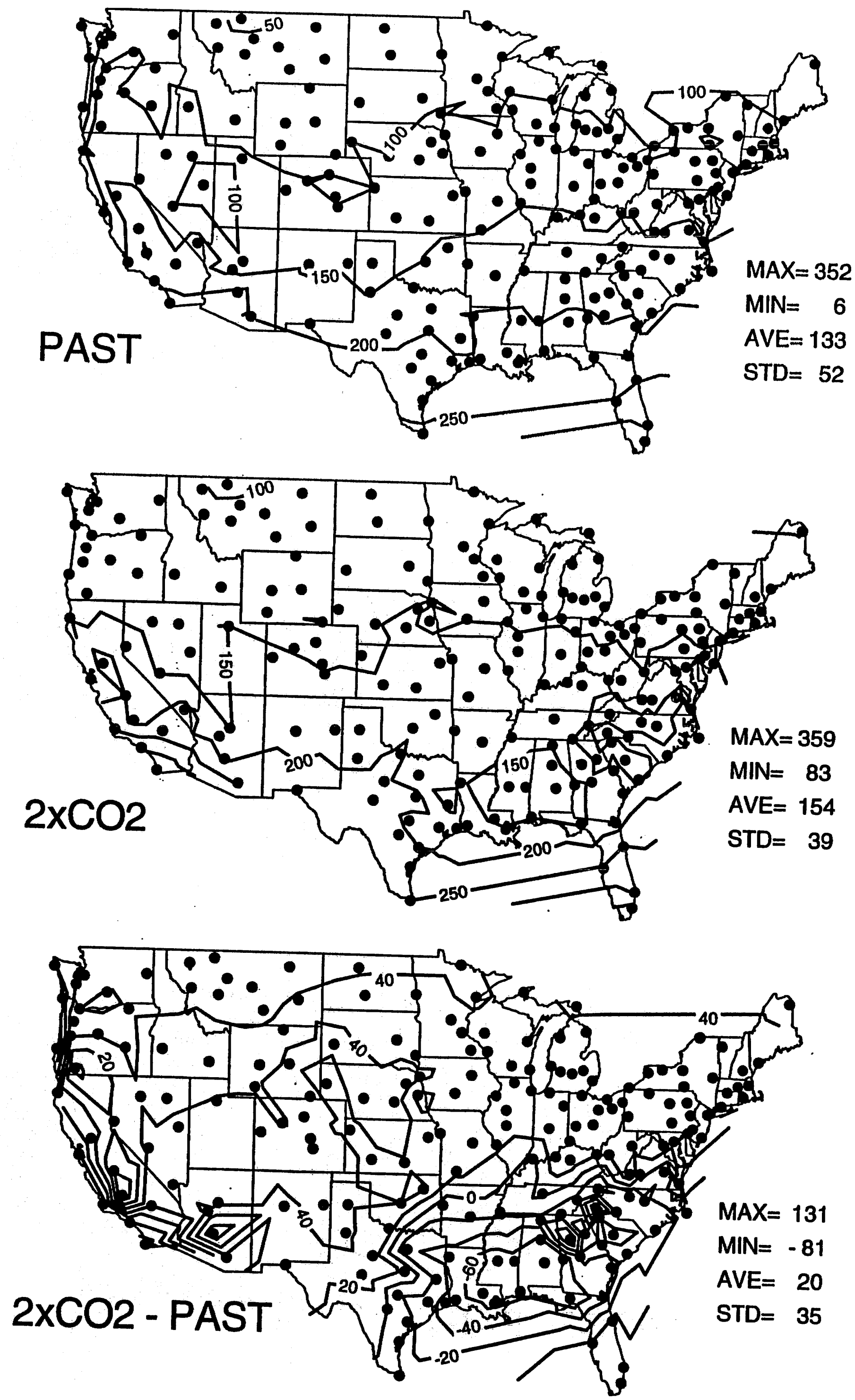

Fig. 35c Simulated, time integrated and **normalized good-growth habitat areas (days)** of **warmwater fish in** *oligotrophic, shallow, small lakes (Type 3,* A_s*=0.2 km*^{2}*)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

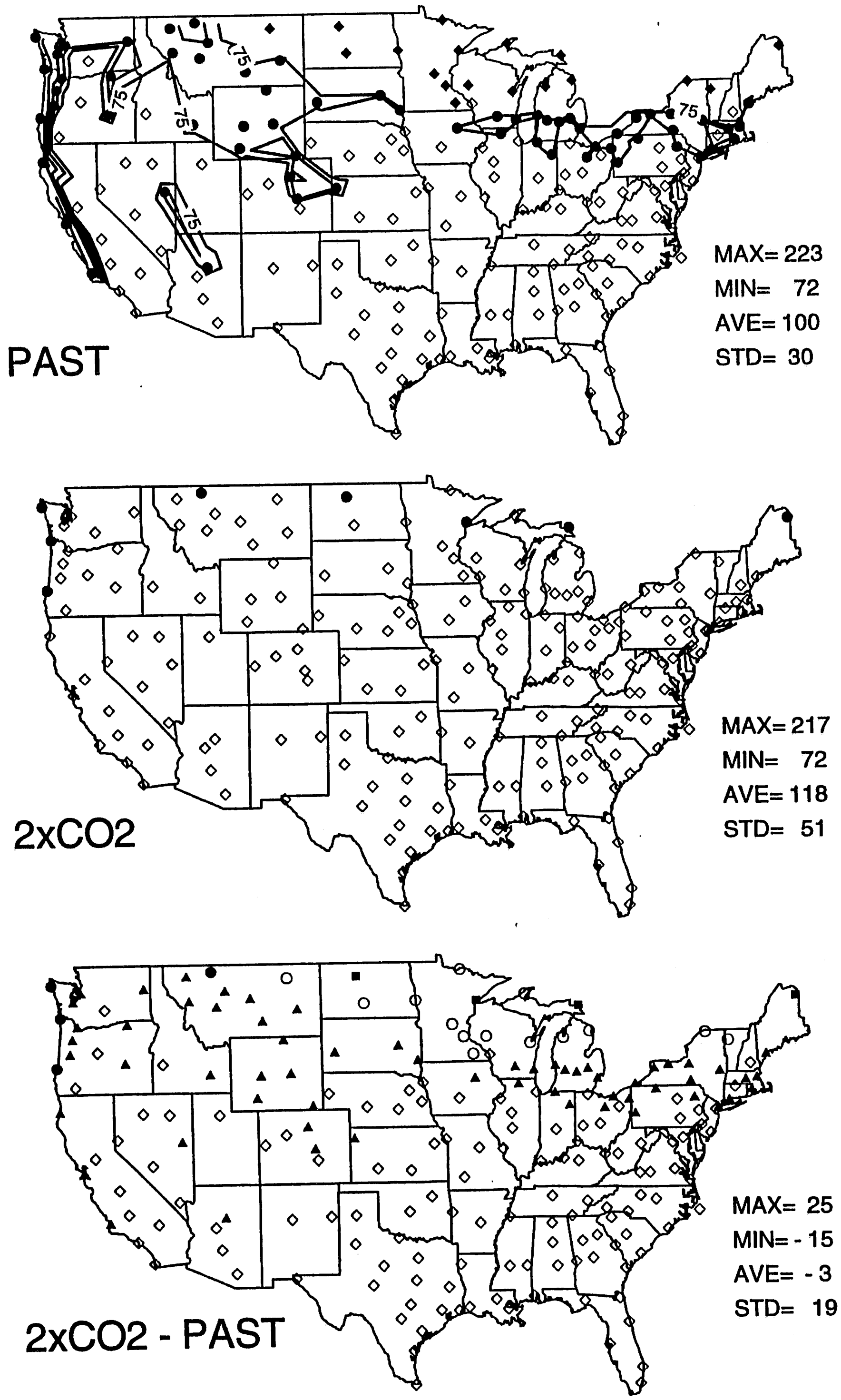

Fig. 36a Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cold-water fish in** *eutrophic, shallow, small lakes (Type 1, A_s=0.2 km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

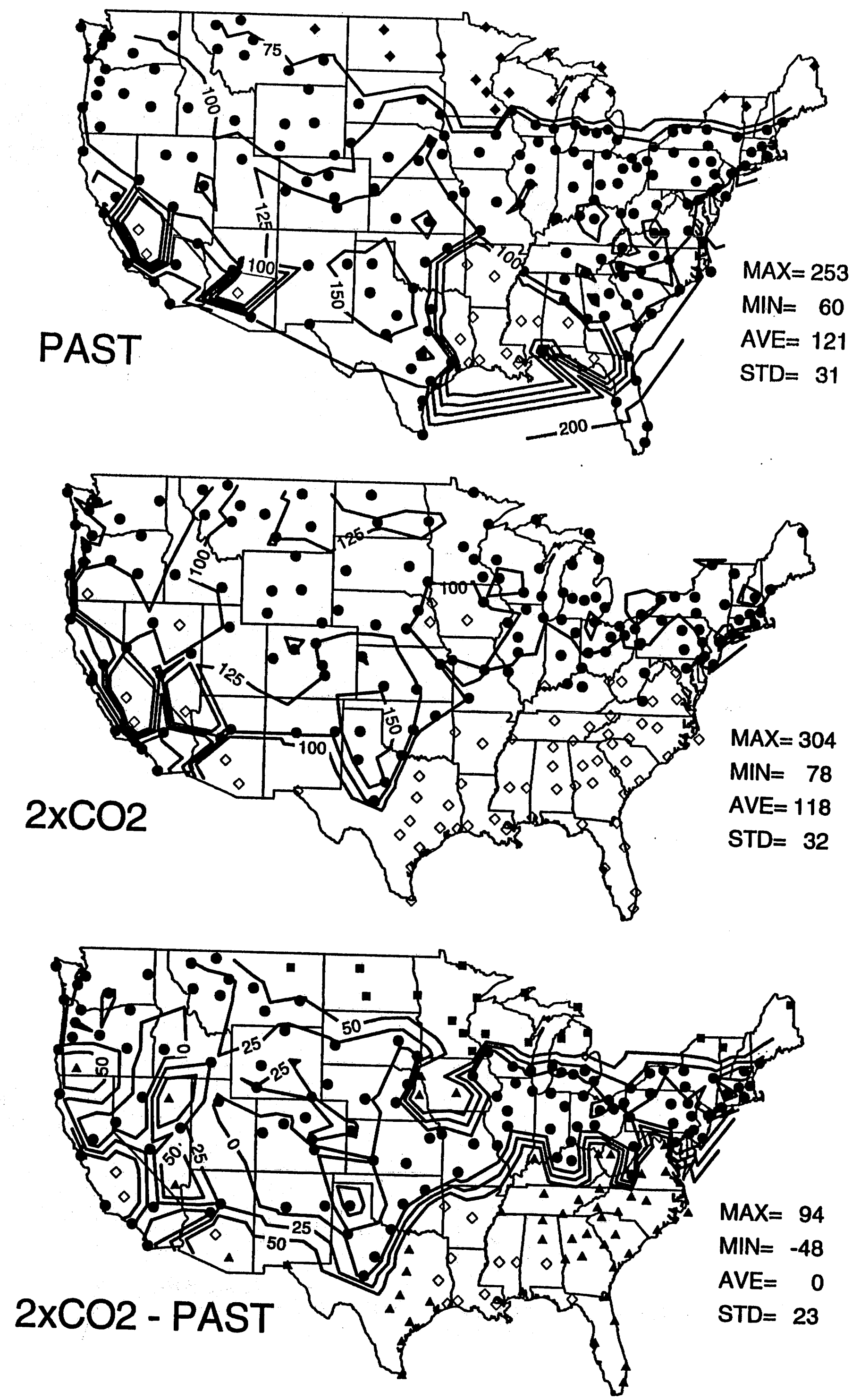

Fig. 36b Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cool-water fish in** *eutrophic, shallow, small lakes (Type 1, $A_s=0.2$ km^2)* under past (1962-1979)(top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

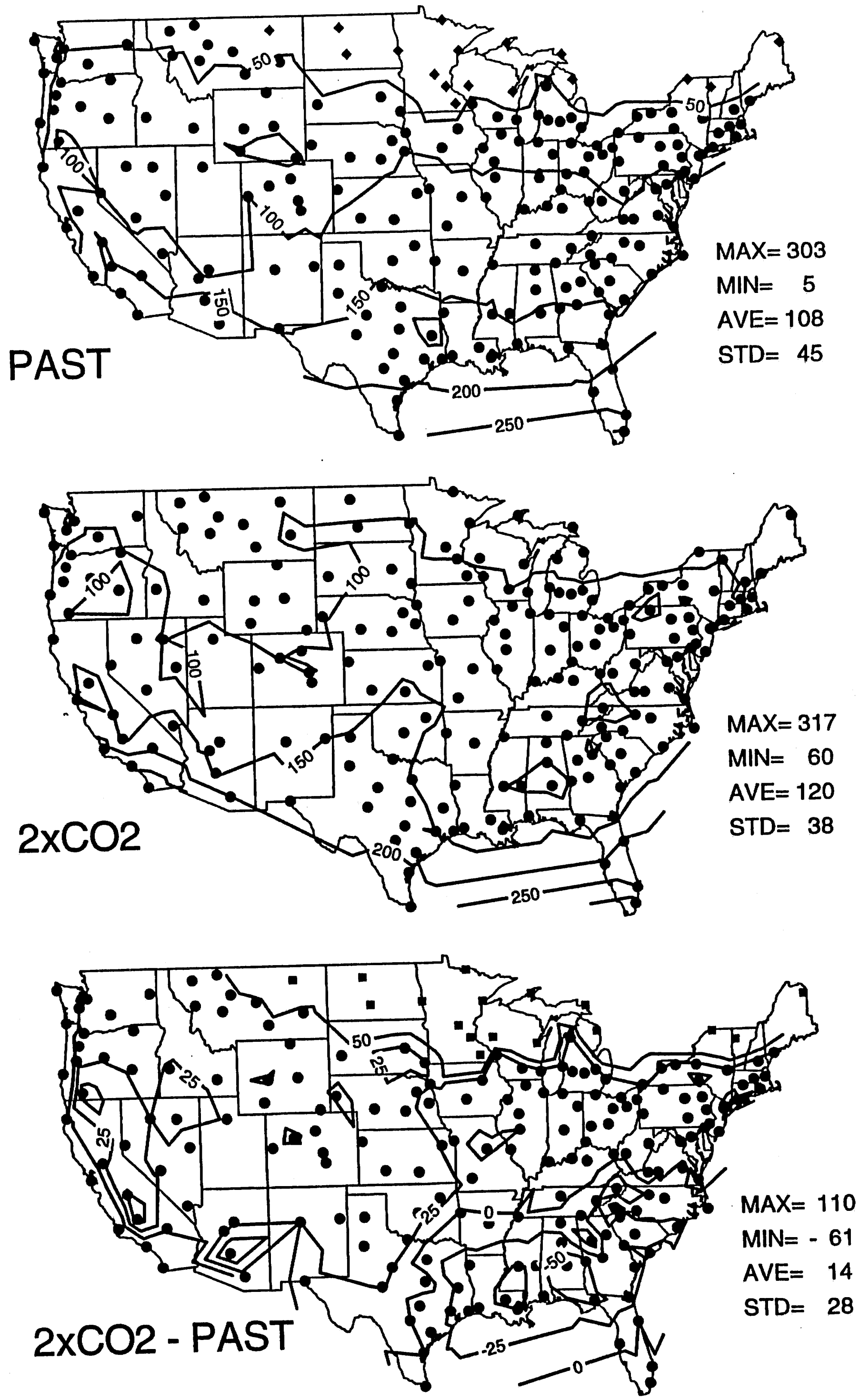

Fig. 36c Simulated, time integrated and **normalized good-growth habitat areas (days)** of **warmwater fish in** *eutrophic, shallow, small lakes (Type 1, A_s=0.2 km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

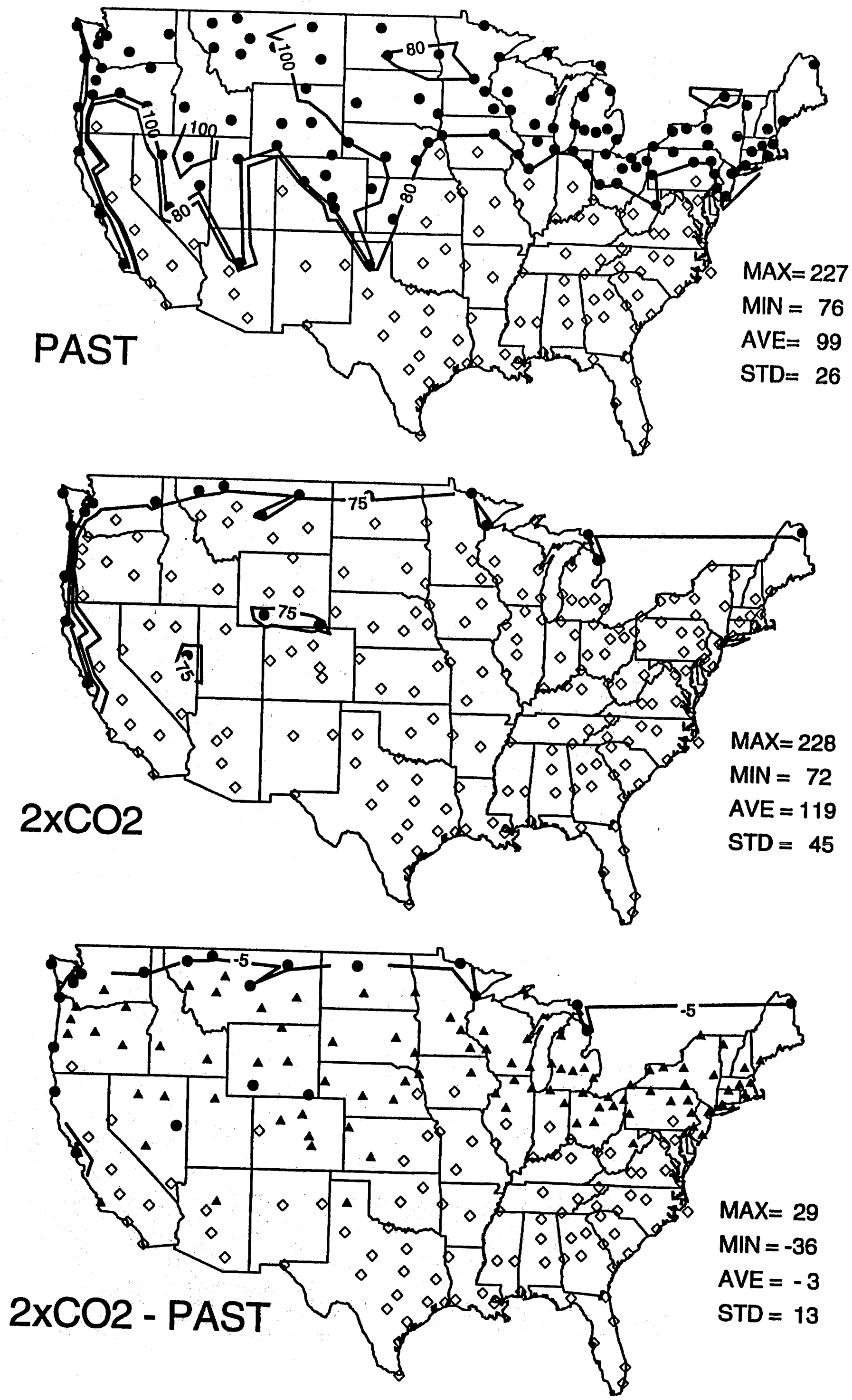

Fig. 37a Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cold-water fish in** *oligotrophic, medium-depth and -size lakes (Type 15,* A_s*=1.7km²)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

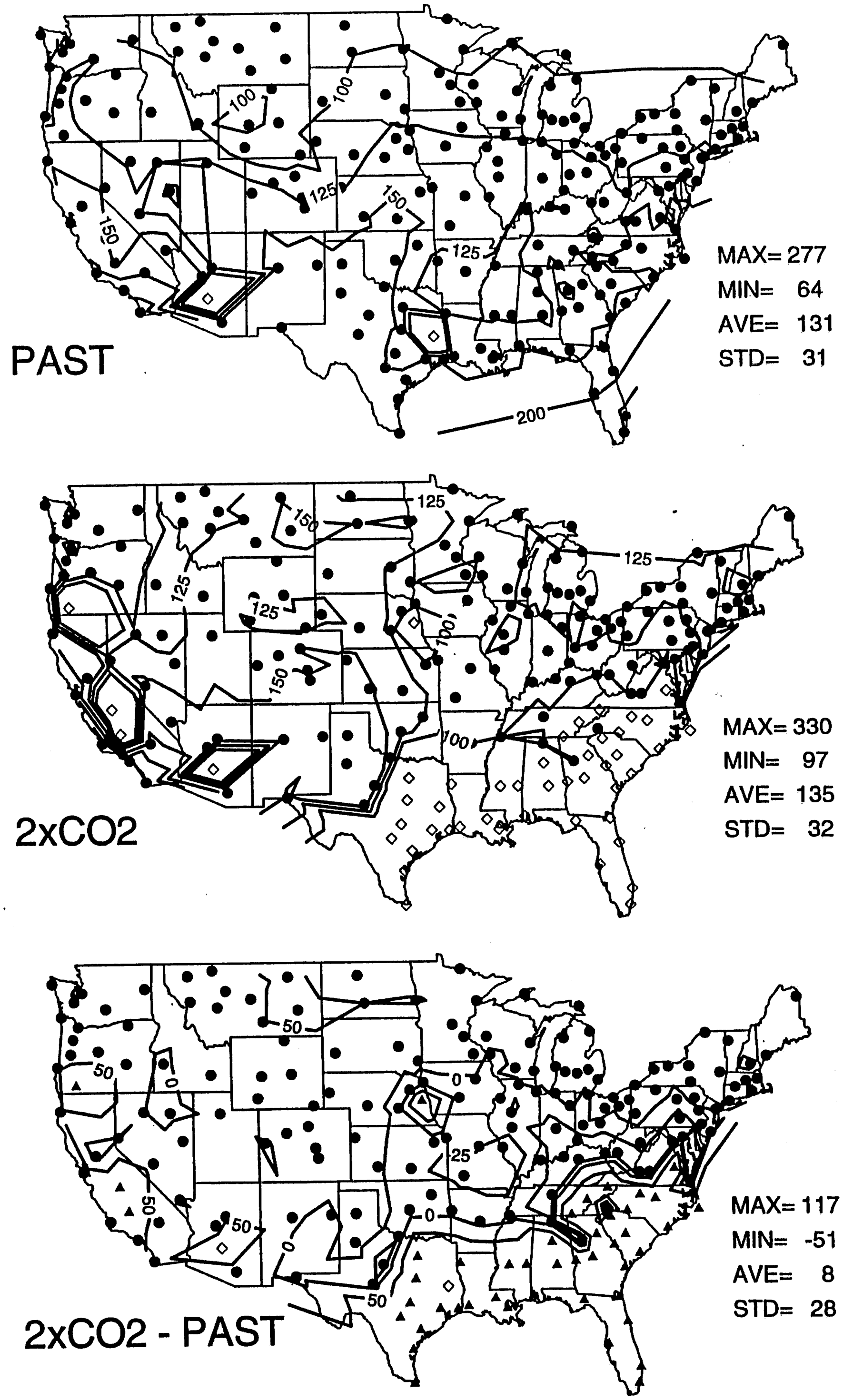

Fig. 37b Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cool-water fish in** *oligotrophic, medium-depth and -size lakes (Type 15, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

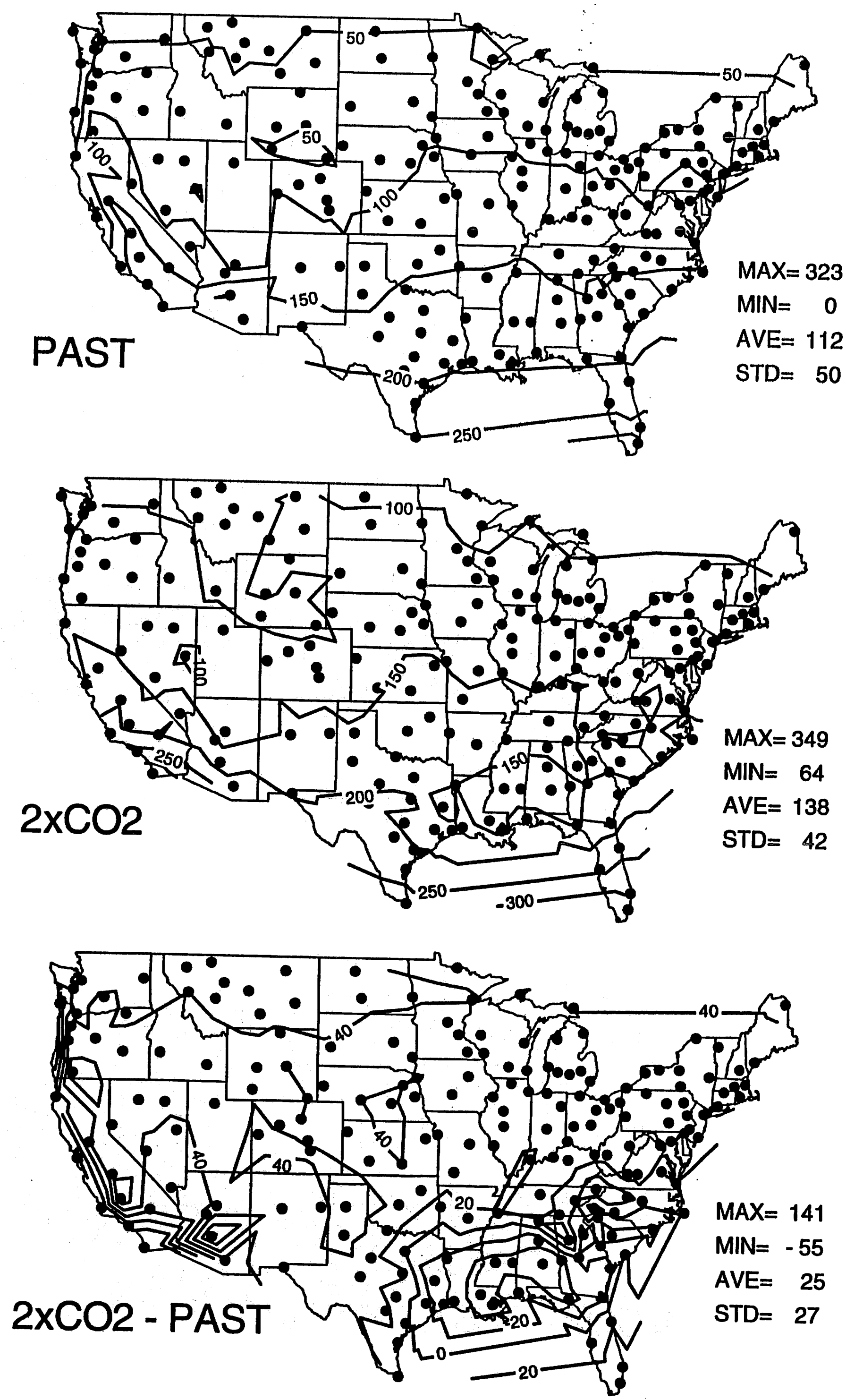

Fig. 37c Simulated, time integrated and **normalized good-growth habitat areas (days)** of **warmwater fish in** *oligotrophic, medium-depth and -size lakes (Type 15, A_s=1.7km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

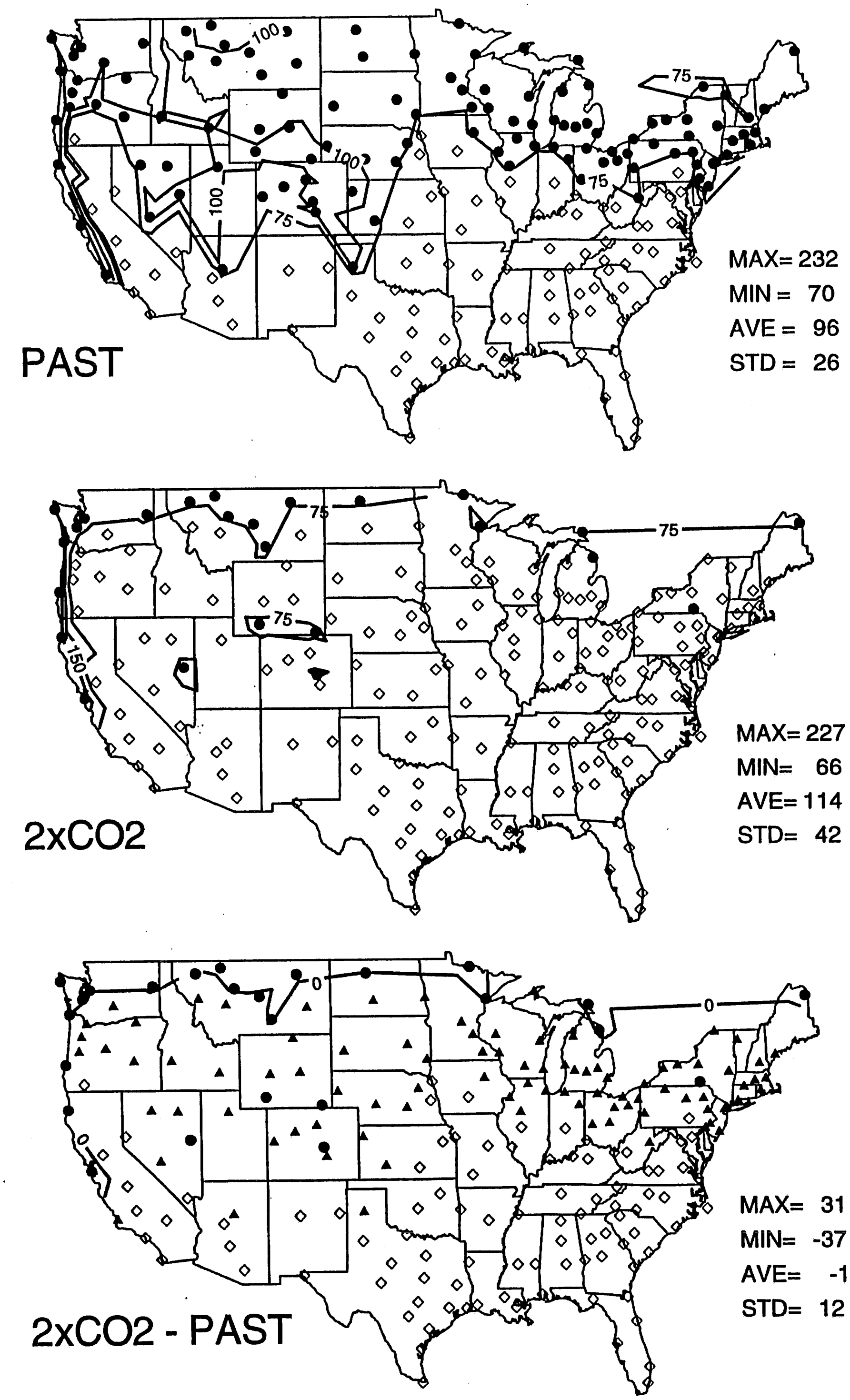

Fig. 38a Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cold-water fish in** *eutrophic, medium-depth and -size lakes (Type 13, A_s=1.7km²)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

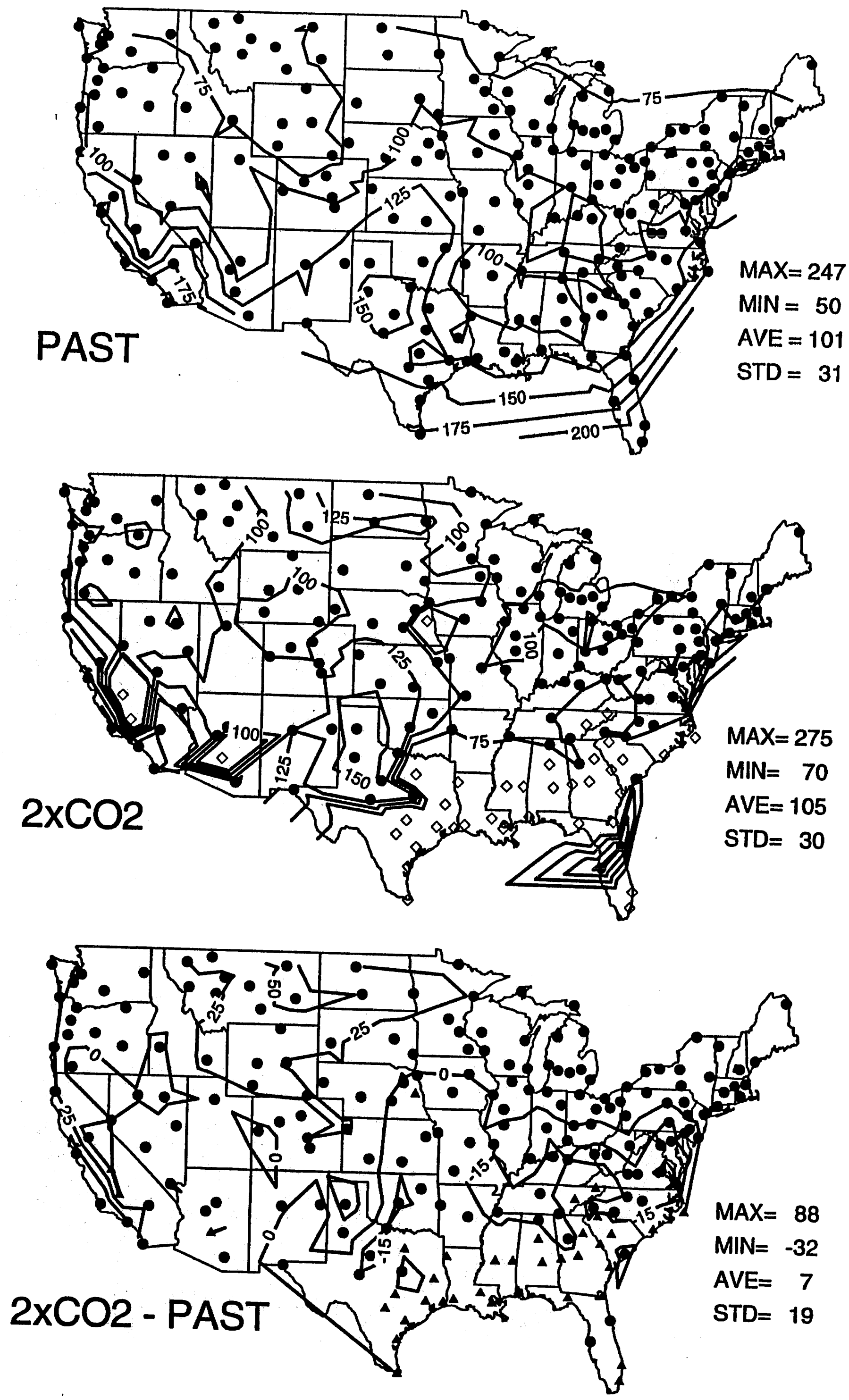

Fig. 38b Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cool-water fish in** *eutrophic, medium-depth and -size lakes (Type 13, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

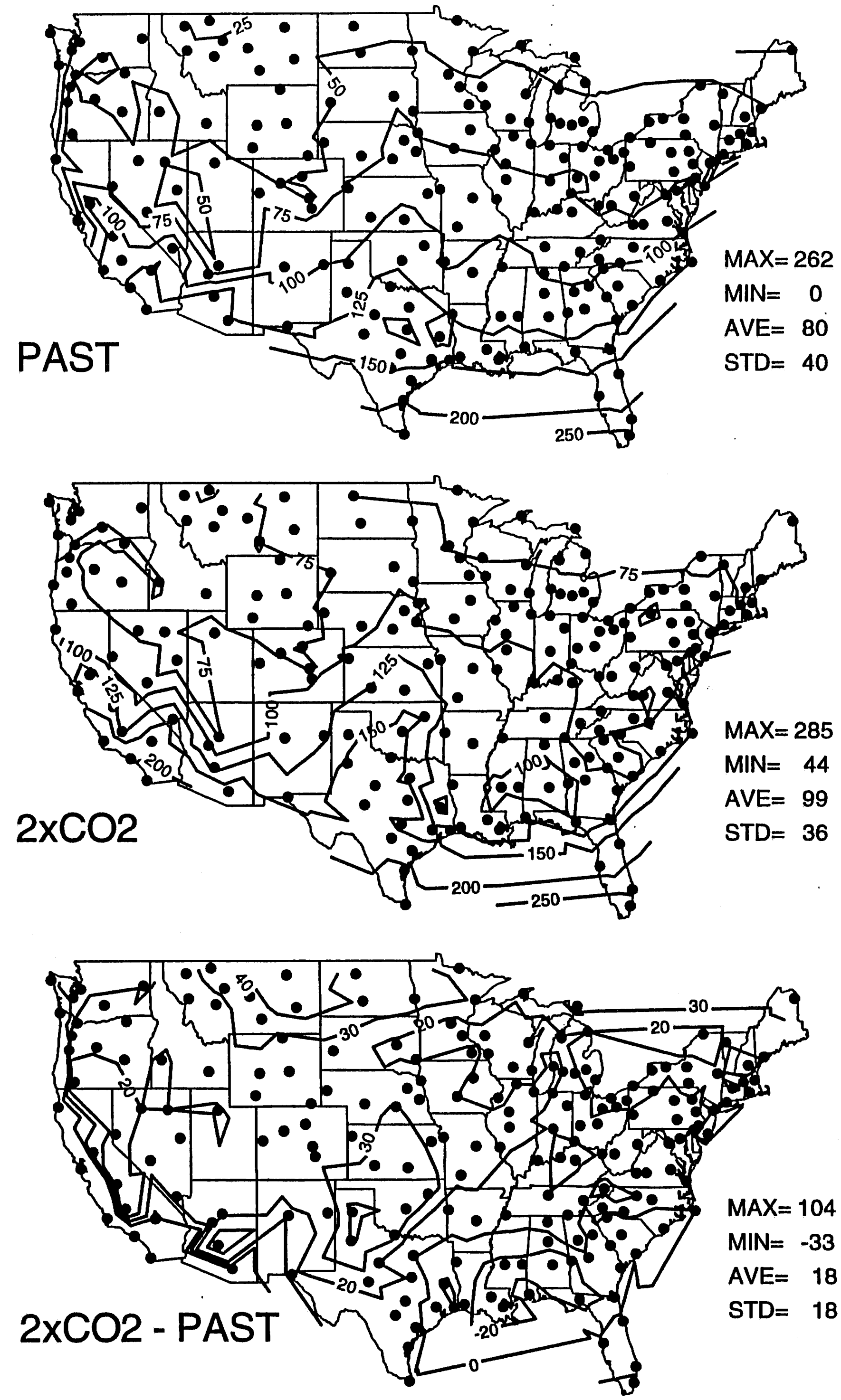

Fig. 38c Simulated, time integrated and **normalized good-growth habitat areas (days)** of **warmwater fish in** *eutrophic, medium-depth and -size lakes (Type 13, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

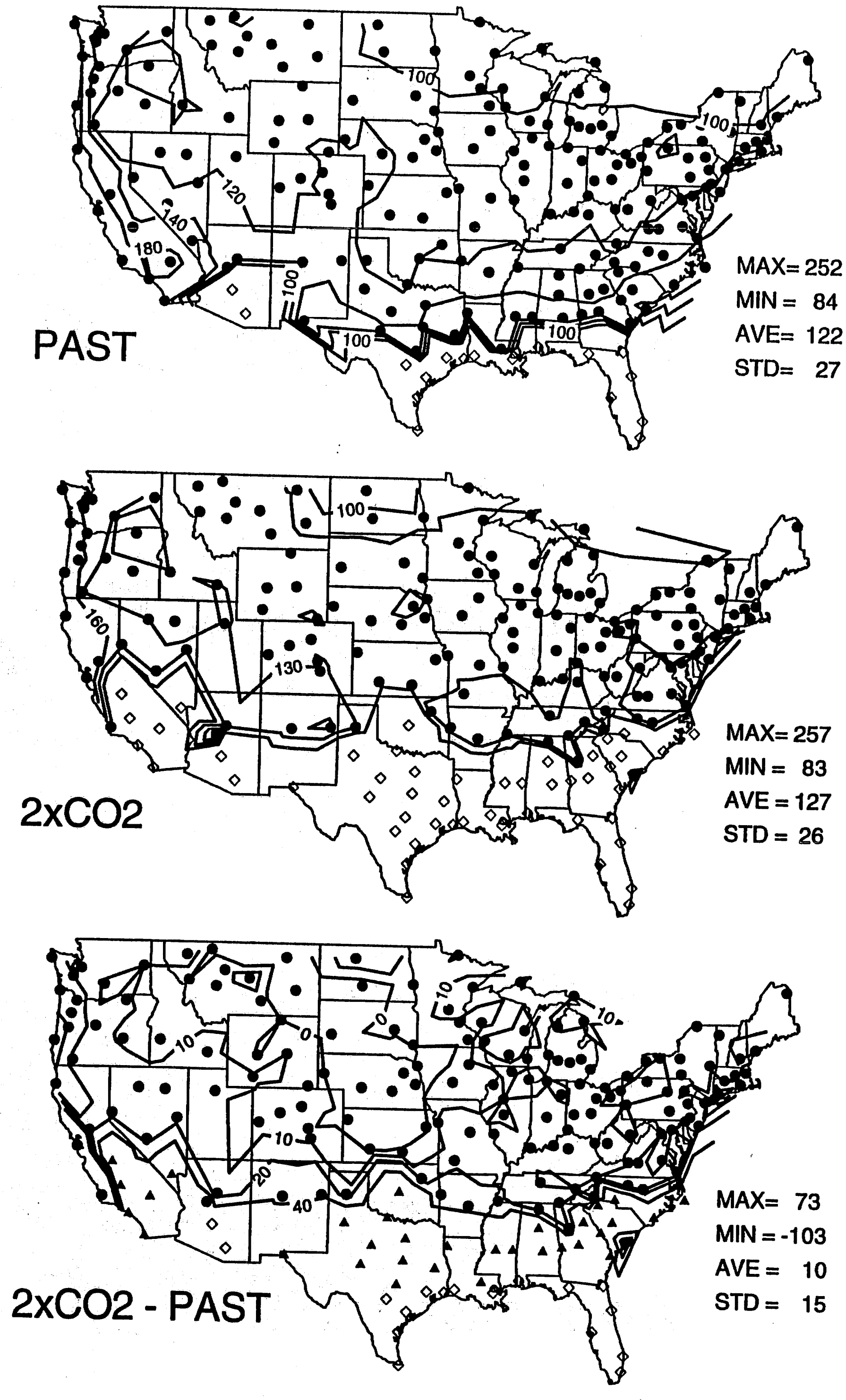

Fig. 39a Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cold-water fish in** *oligotrophic, deep, medium-size lakes (Type 24,* $A_s=1.7km^2$*)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

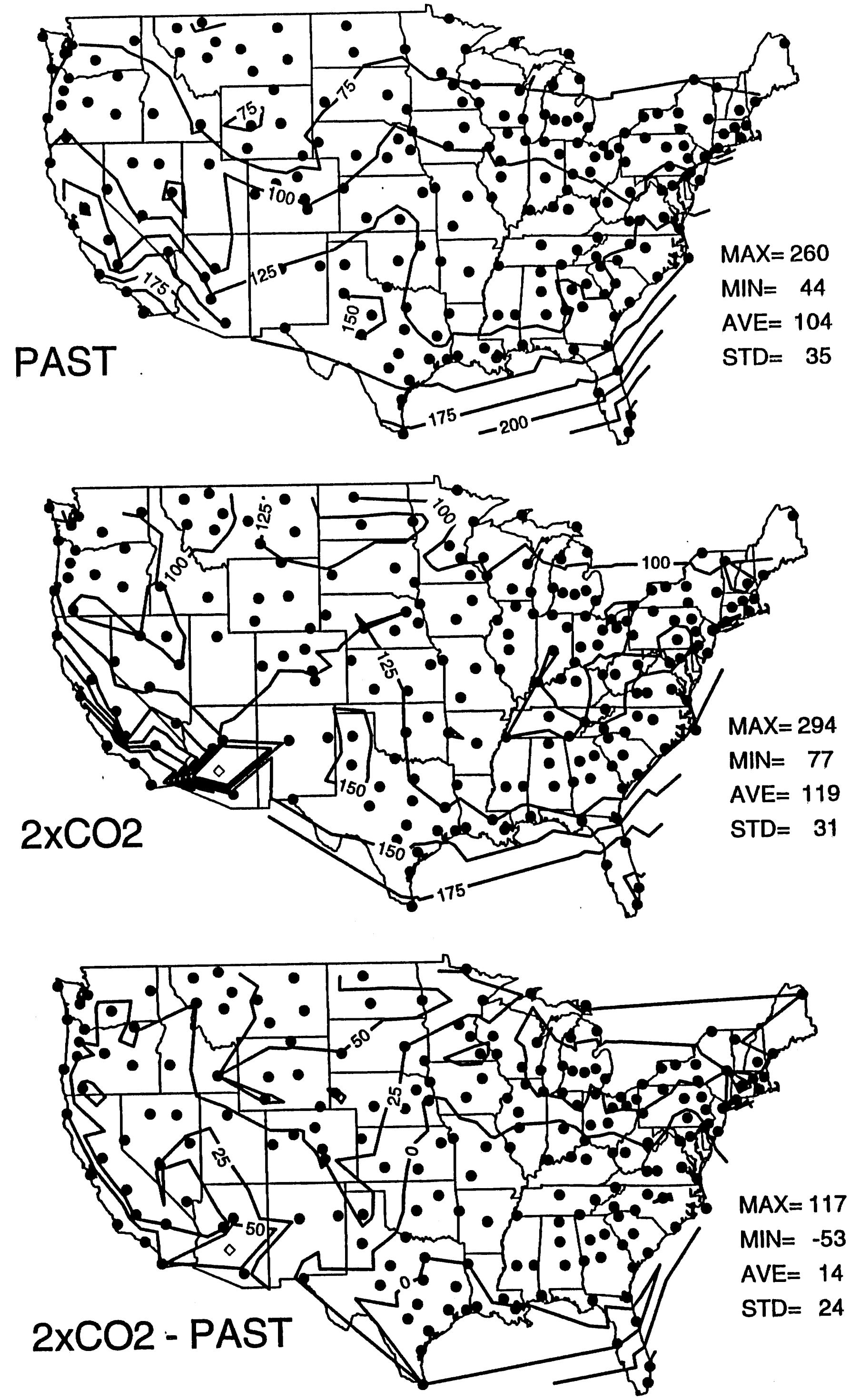

Fig. 39b Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cool-water fish in** *oligotrophic, deep, medium-size lakes (Type 24, A_s=1.7km²)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

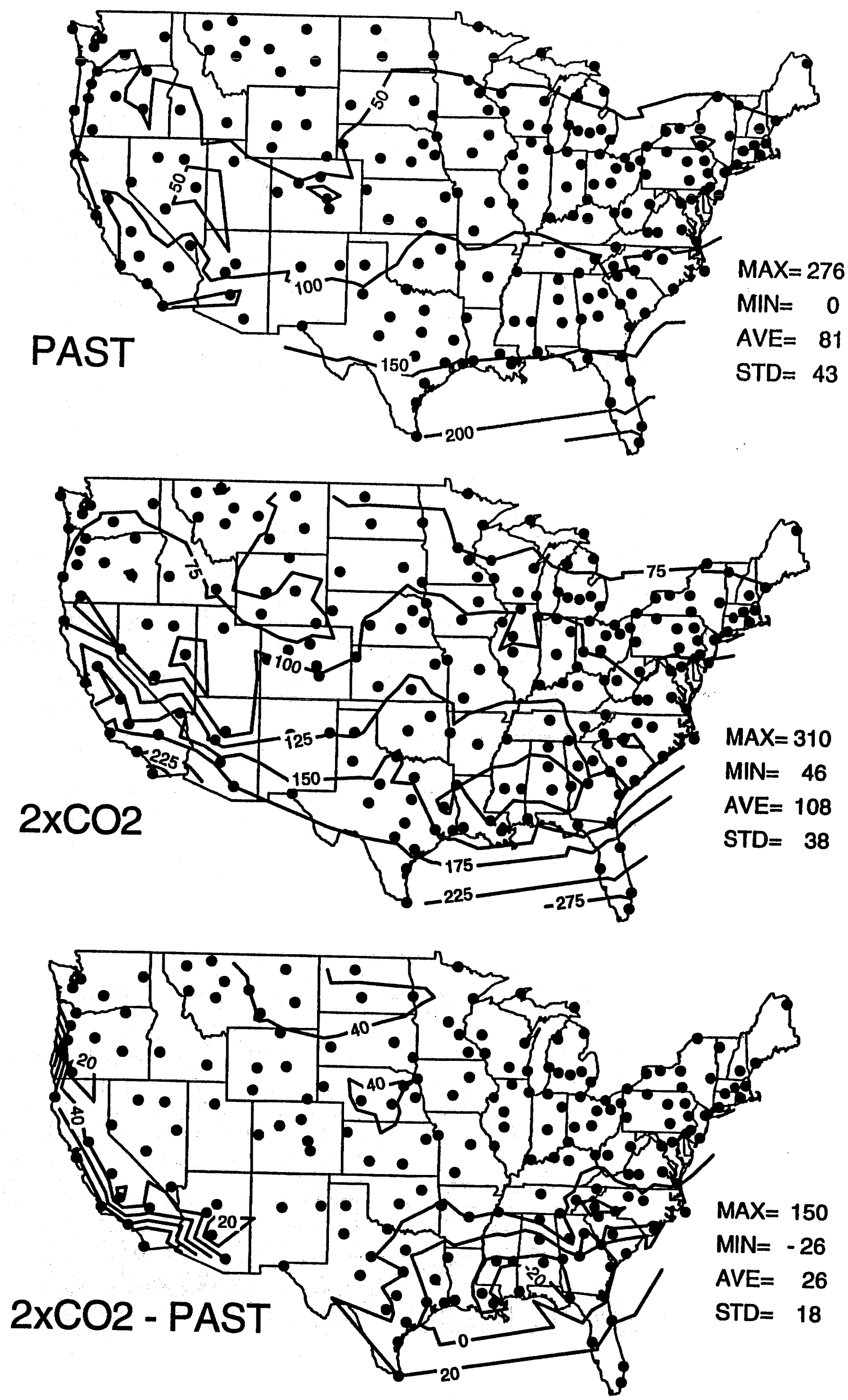

Fig. 39c Simulated, time integrated and **normalized good-growth habitat areas (days)** of **warmwater fish in** *oligotrophic, deep, medium-size lakes (Type 24,* A_s*=1.7km²)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

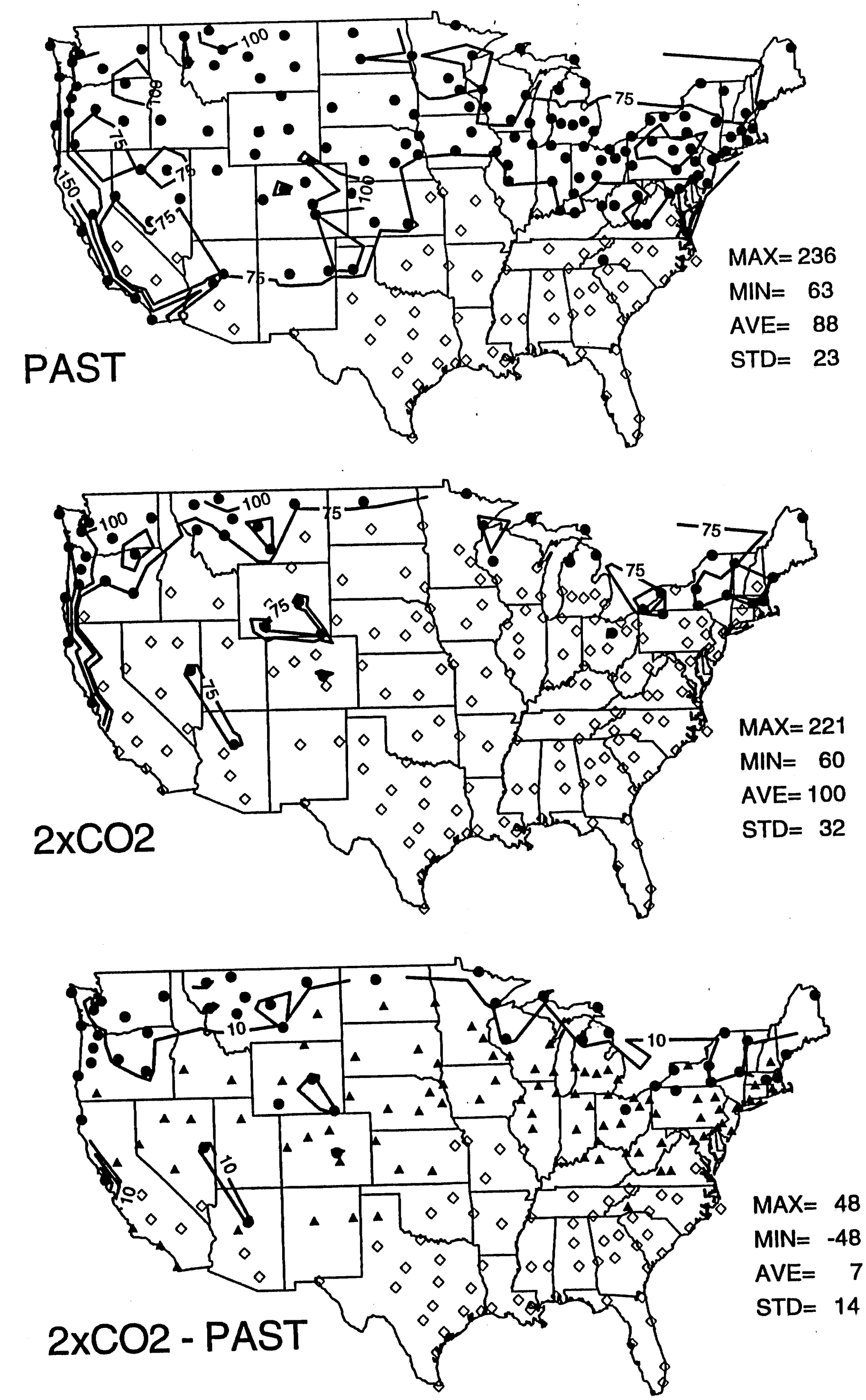

Fig. 40a Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cold-water fish in** *eutrophic, deep, medium-size lakes (Type 22, A_s=1.7km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

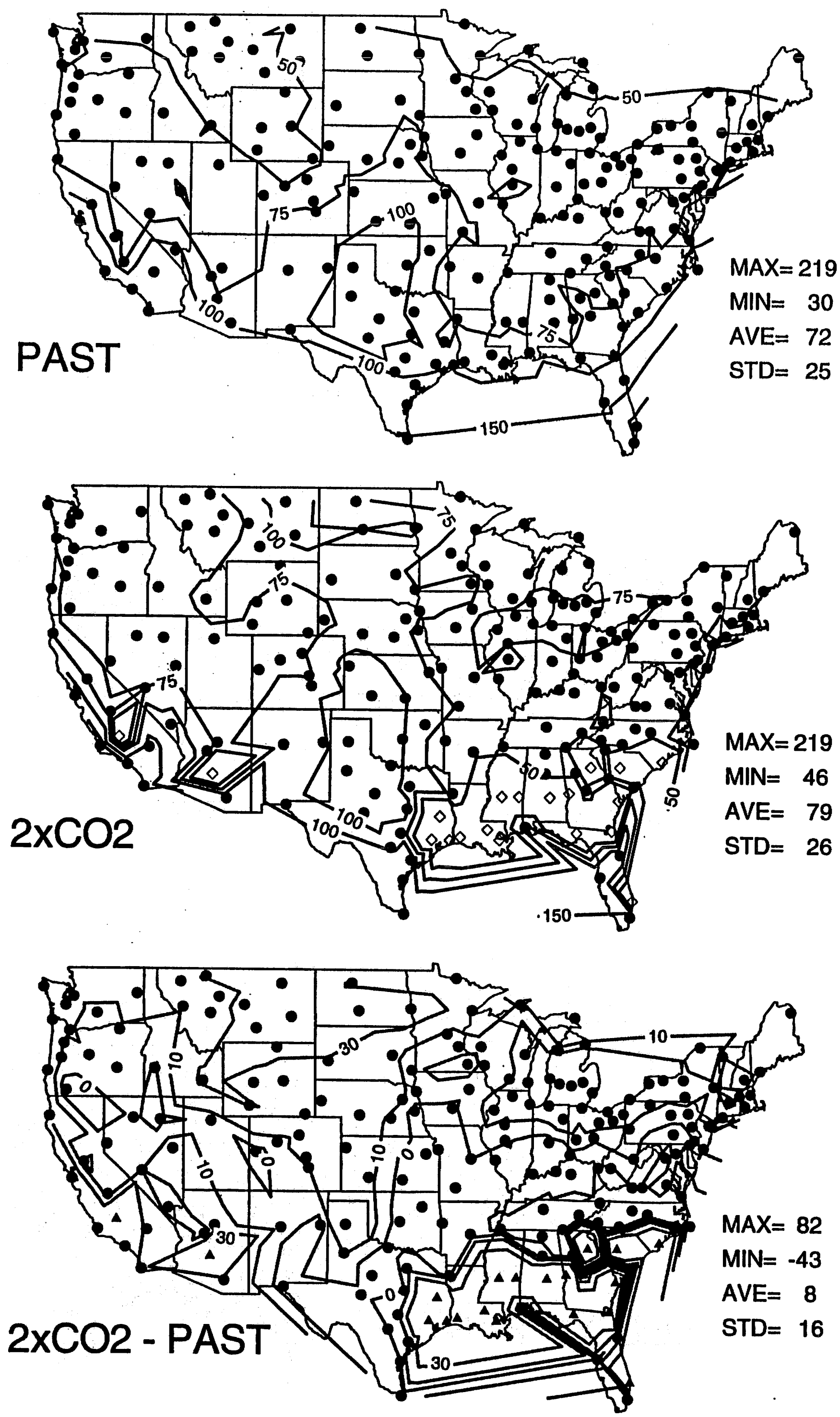

Fig. 40b Simulated, time integrated and **normalized good-growth habitat areas (days)** of **cool-water fish in** *eutrophic, deep, medium-size lakes (Type 22, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

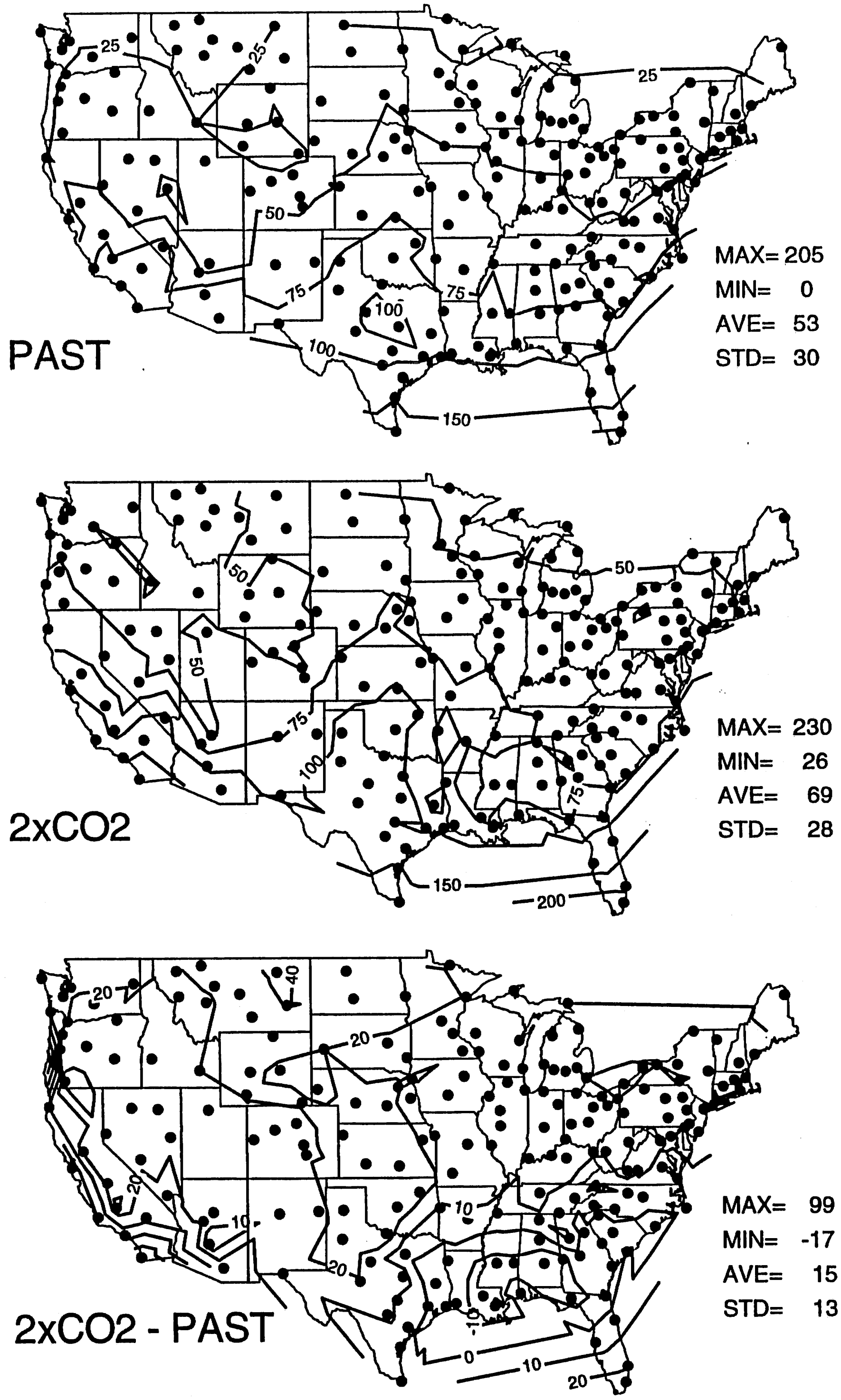

Fig. 40c Simulated, time integrated and **normalized good-growth habitat areas (days)** of **warmwater fish in** *eutrophic, deep, medium-size lakes (Type 22,* $A_s=1.7km^2$*)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

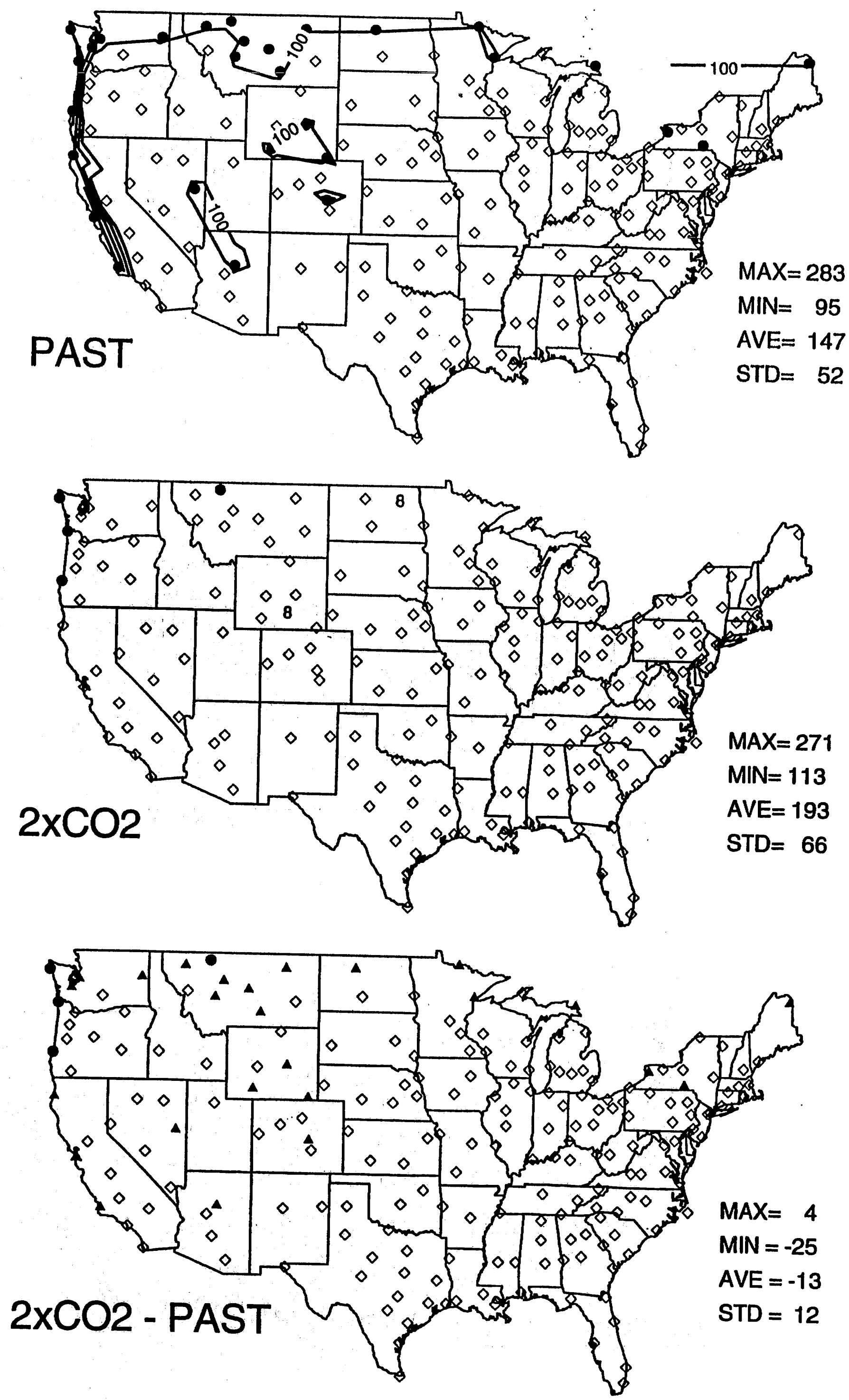

Fig. 41a Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cold-water fish** for *oligotrophic, shallow, large lakes (Type 9,* A_s*=10 km*^{2}*)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

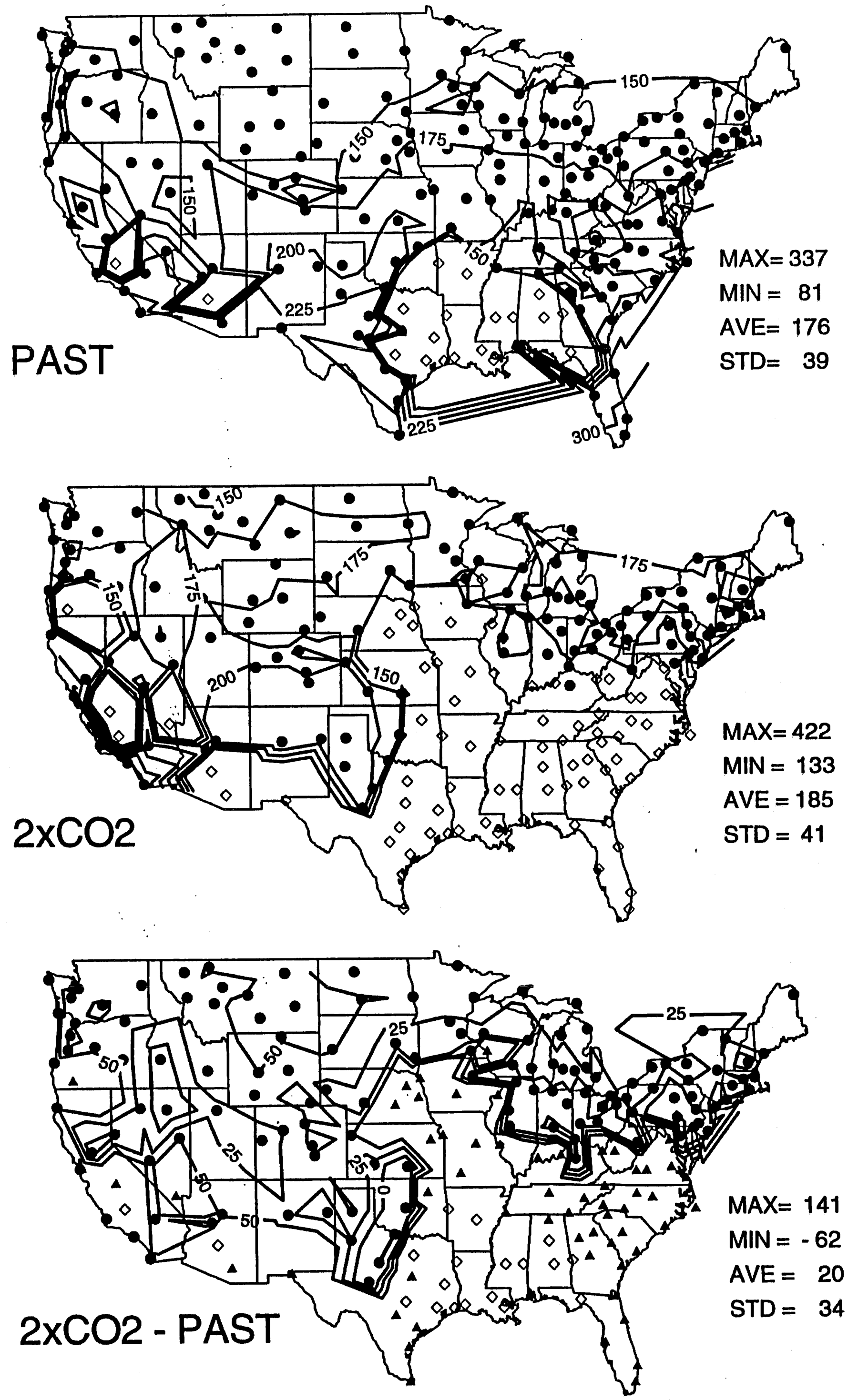

Fig. 41b Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cool-water fish** for *oligotrophic, shallow, large lakes (Type 9, A_s=10 km^2)* under past (1962-1979)(top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

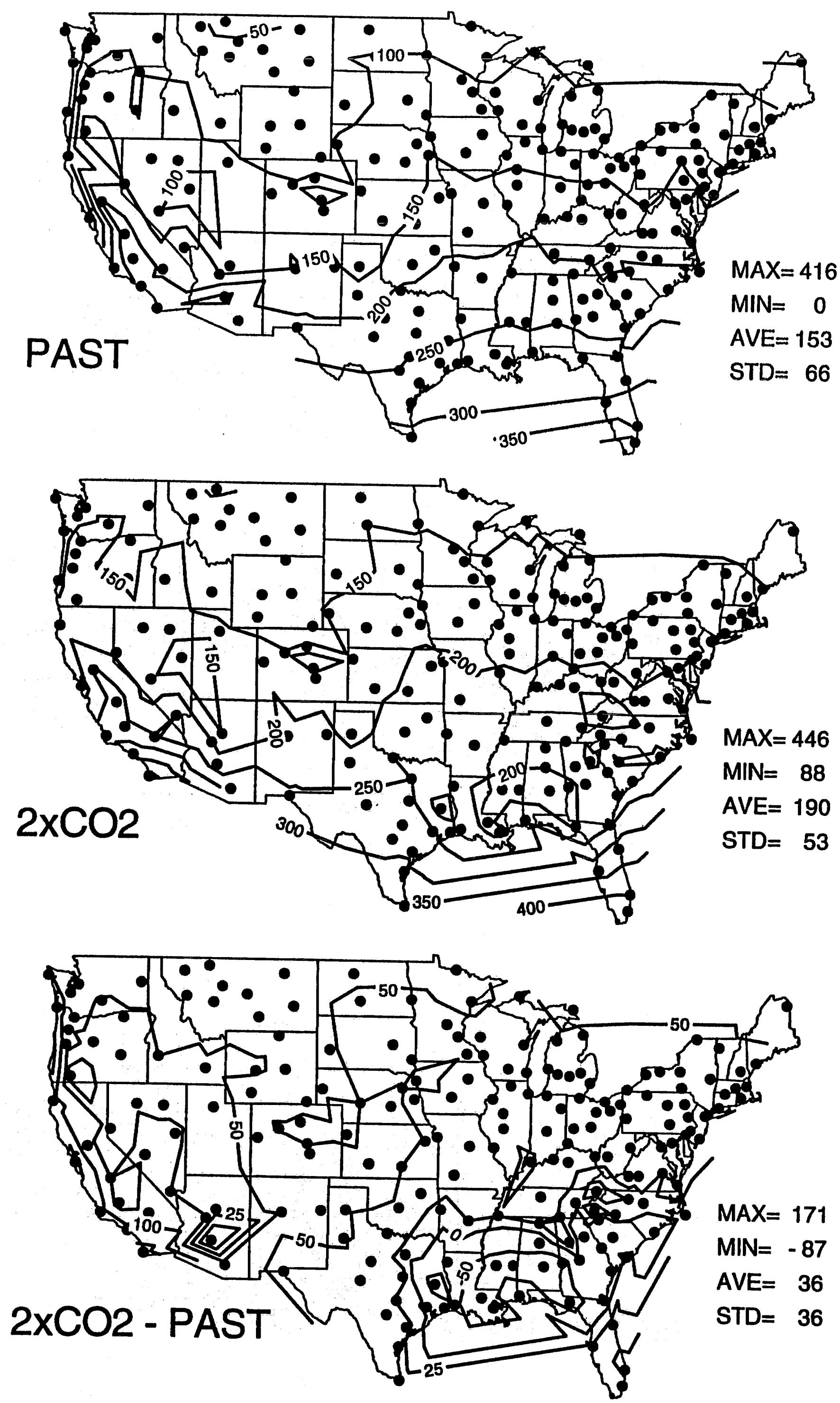

Fig. 41c Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **warmwater fish** for *oligotrophic, shallow, large lakes (Type 9, $A_s=10km^2$)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

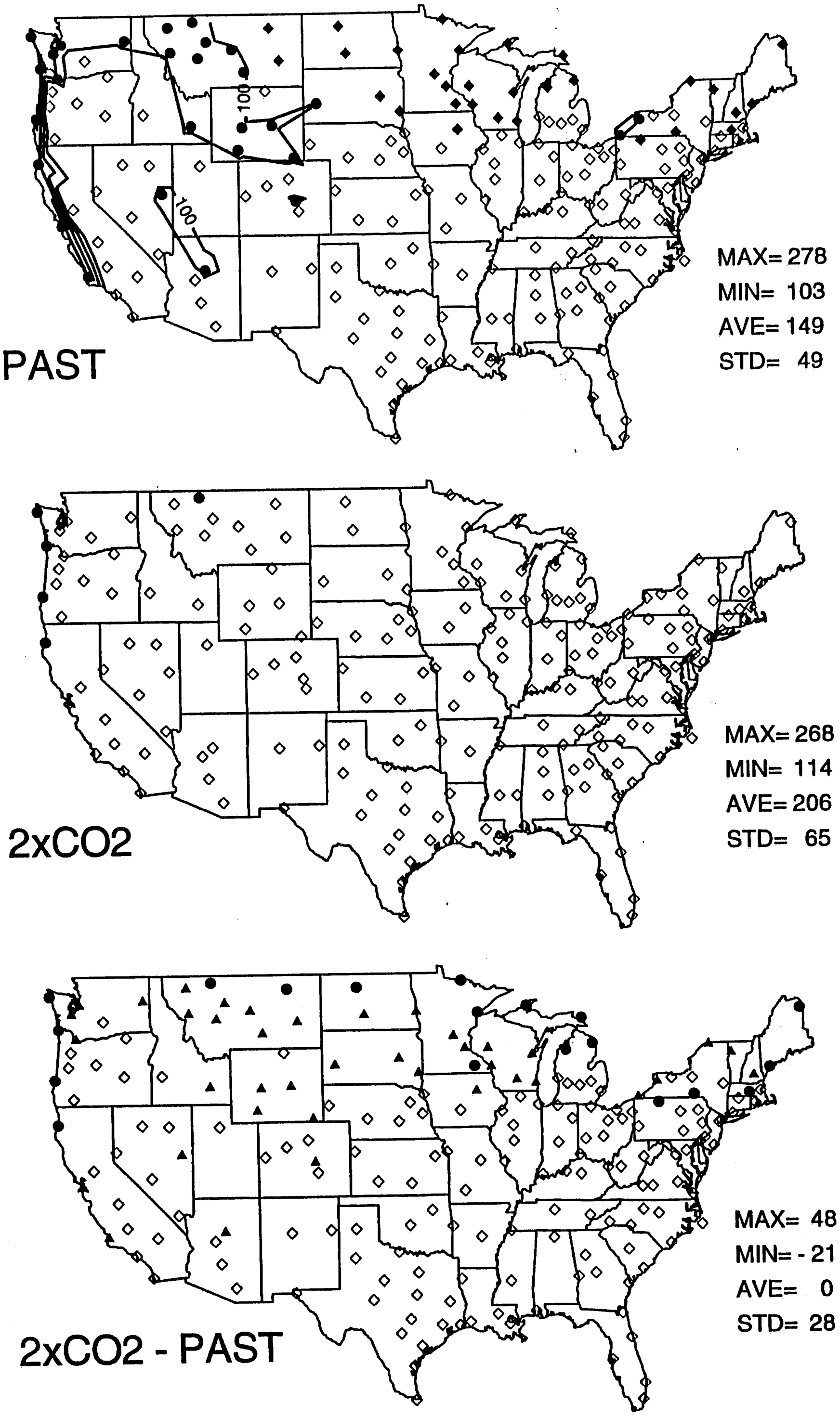

Fig. 42a Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cold-water fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10 km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

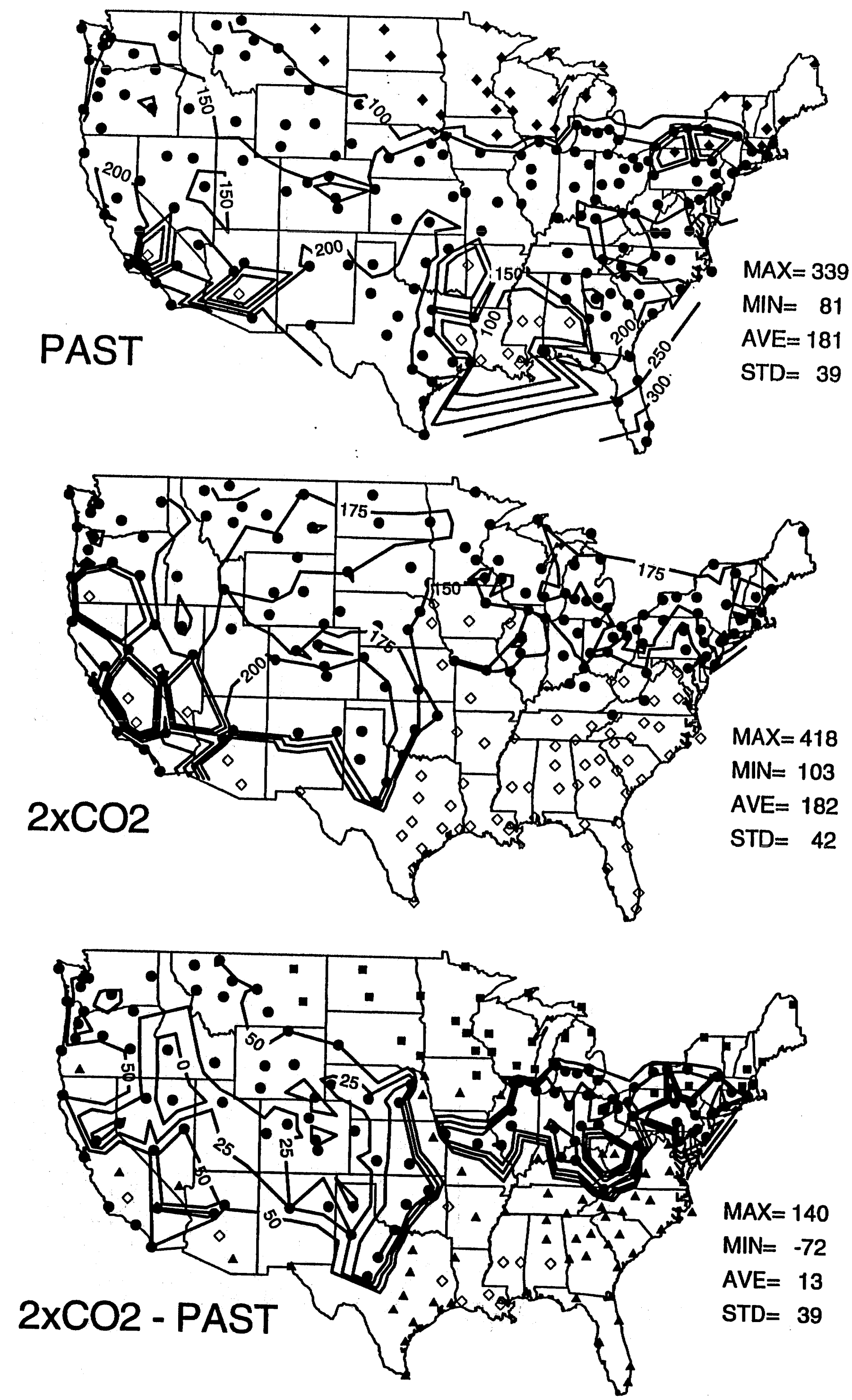

Fig. 42b Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cool-water fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10 km^2)* under past (1962-1979)(top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

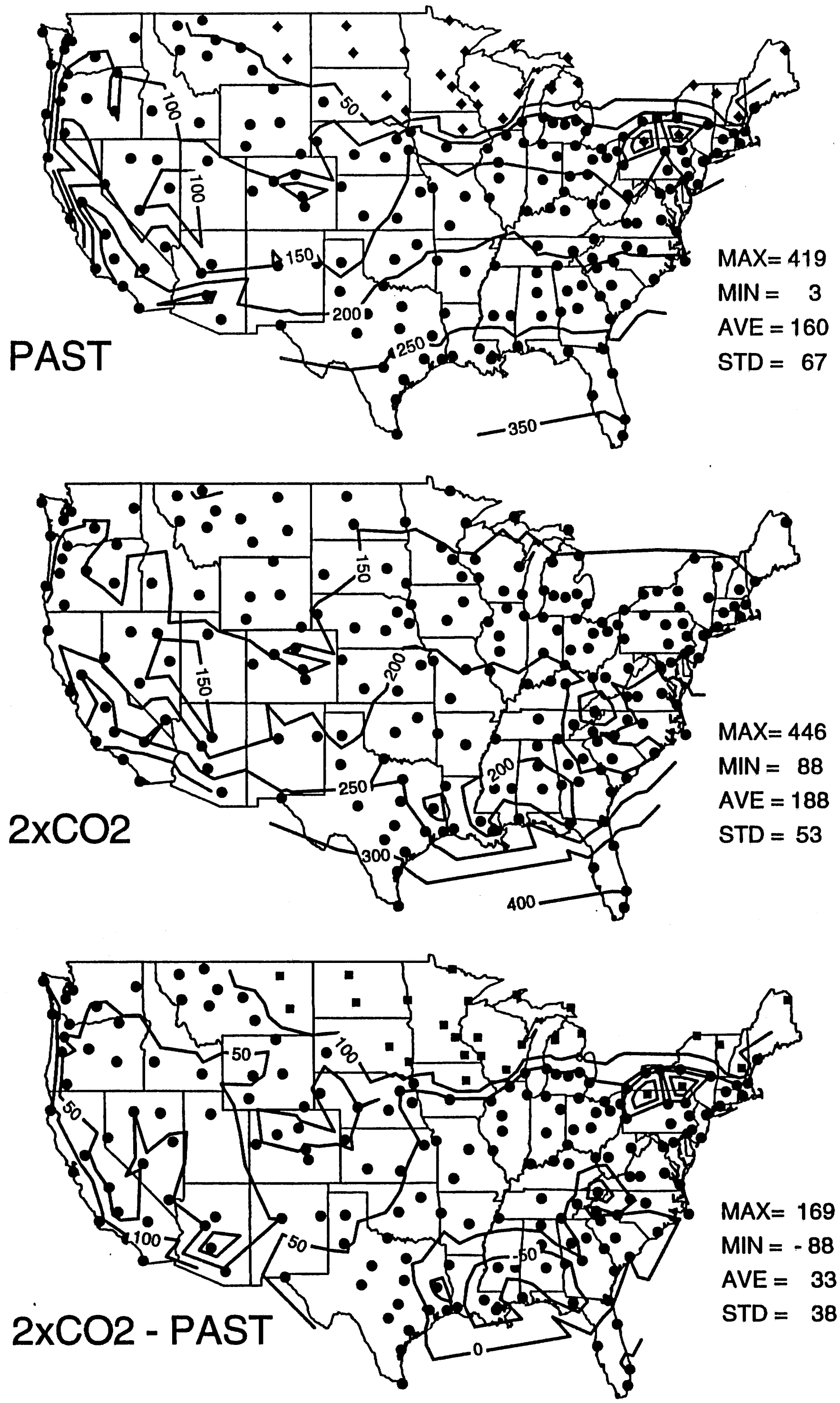

Fig. 42c Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **warmwater fish in** *eutrophic, shallow, large lakes (Type 7, A_s=10km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

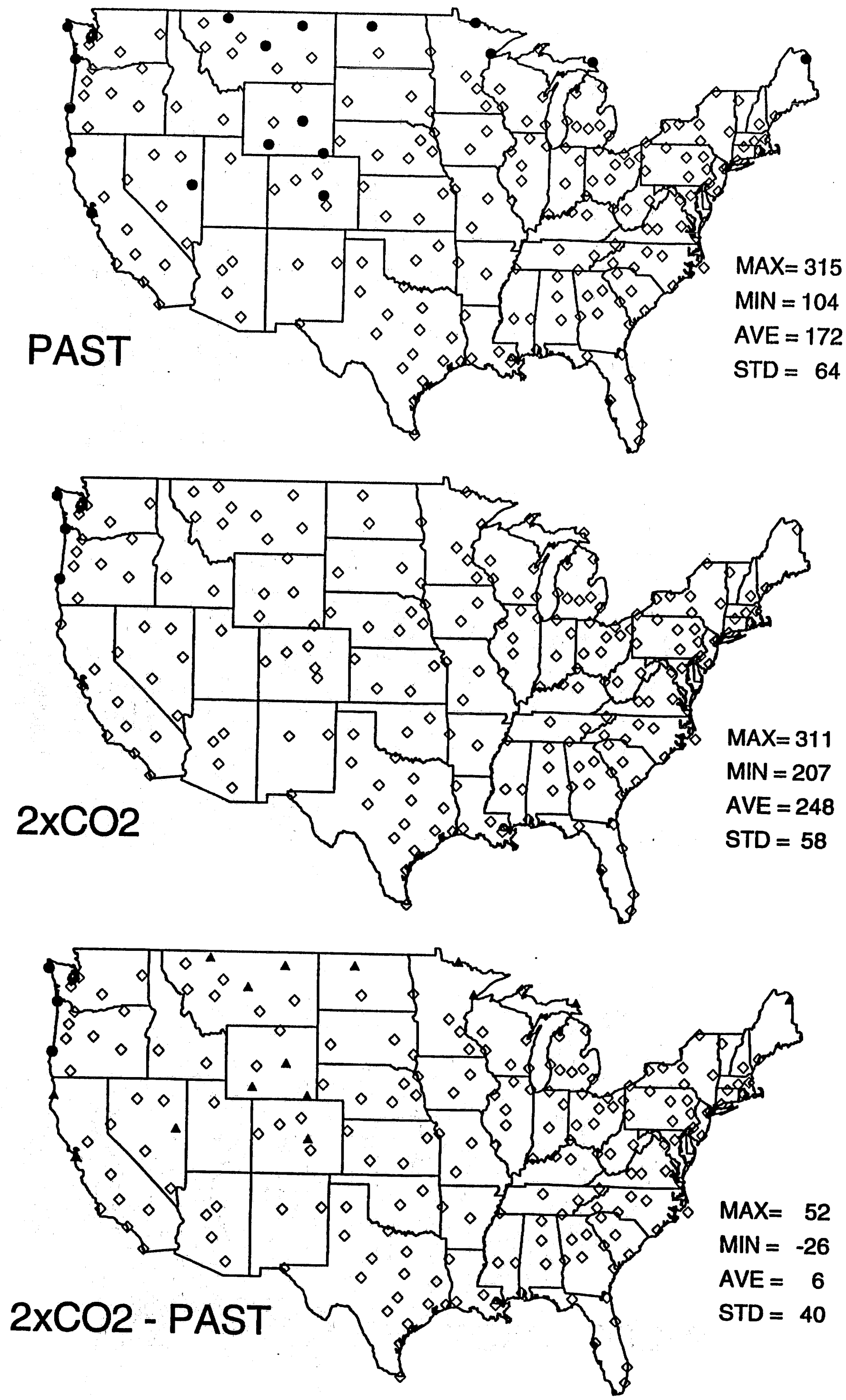

Fig. 43a Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cold-water fish in** *oligotrophic, shallow, small lakes (Type 3, A_s=0.2 km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

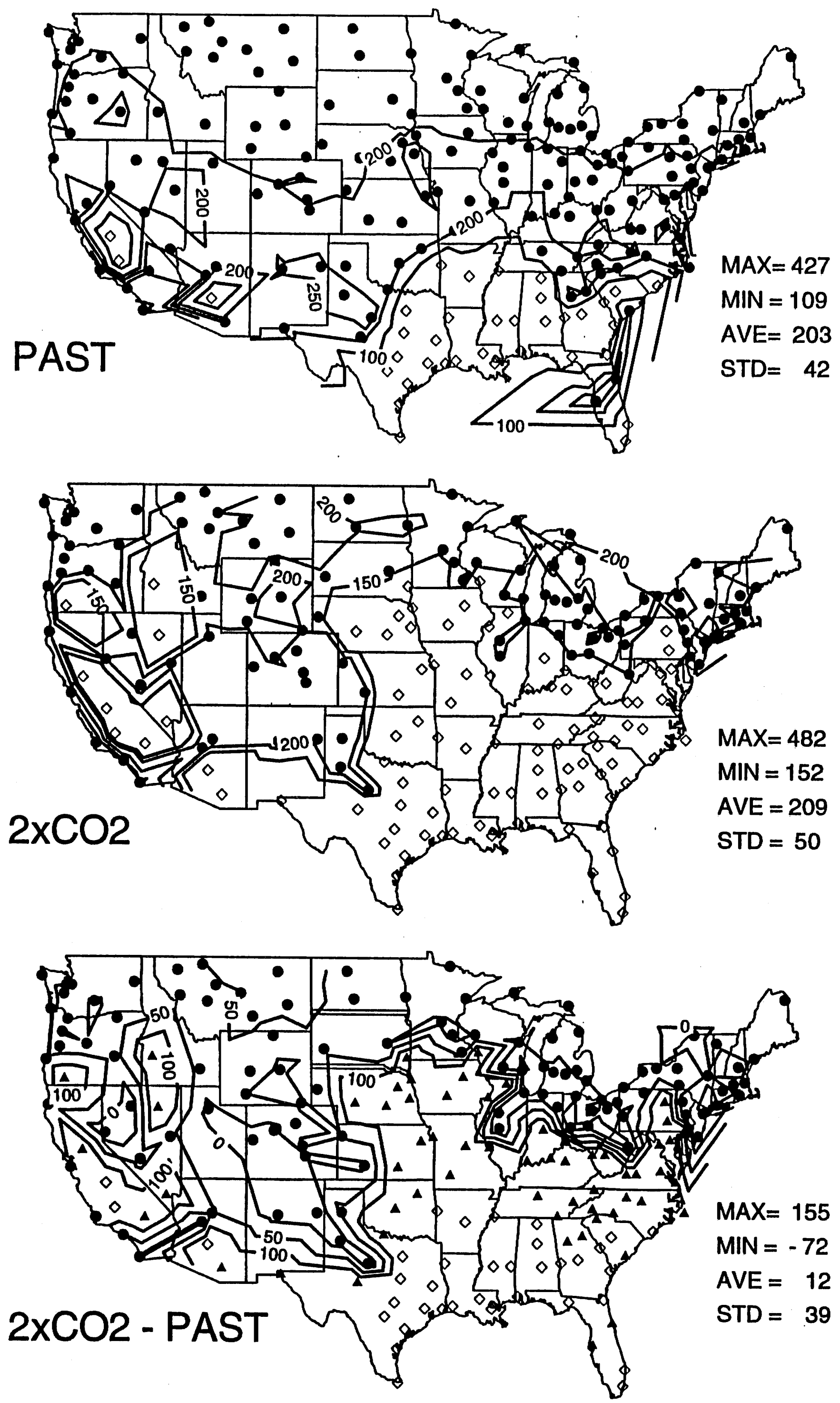

Fig. 43b Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cool-water fish in** *oligotrophic, shallow, small lakes (Type 3, $A_s=0.2\ km^2$)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

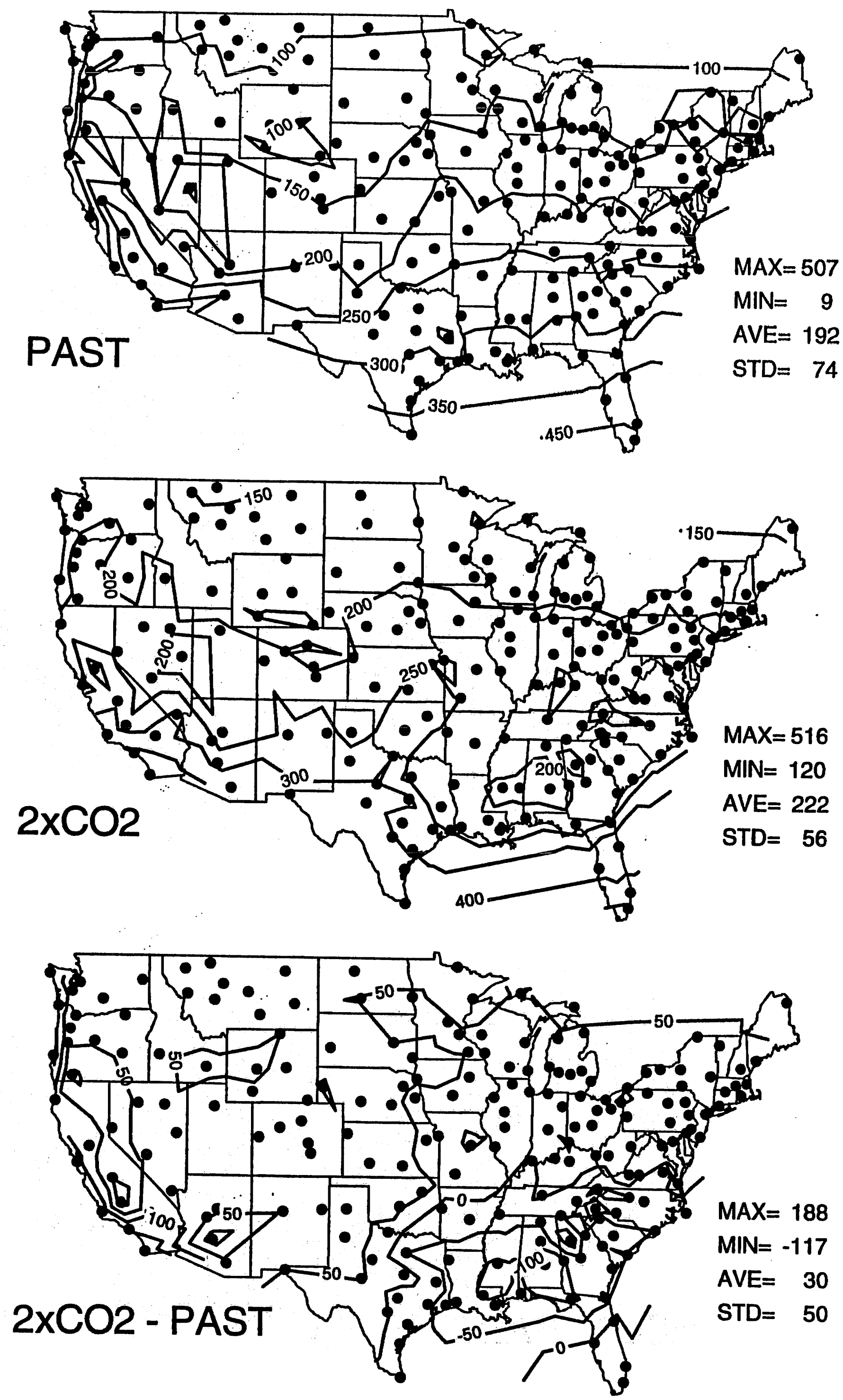

Fig. 43c Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **warmwater fish in** *oligotrophic, shallow, small lakes (Type 3,* A_s*=0.2 km*^{2}*)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

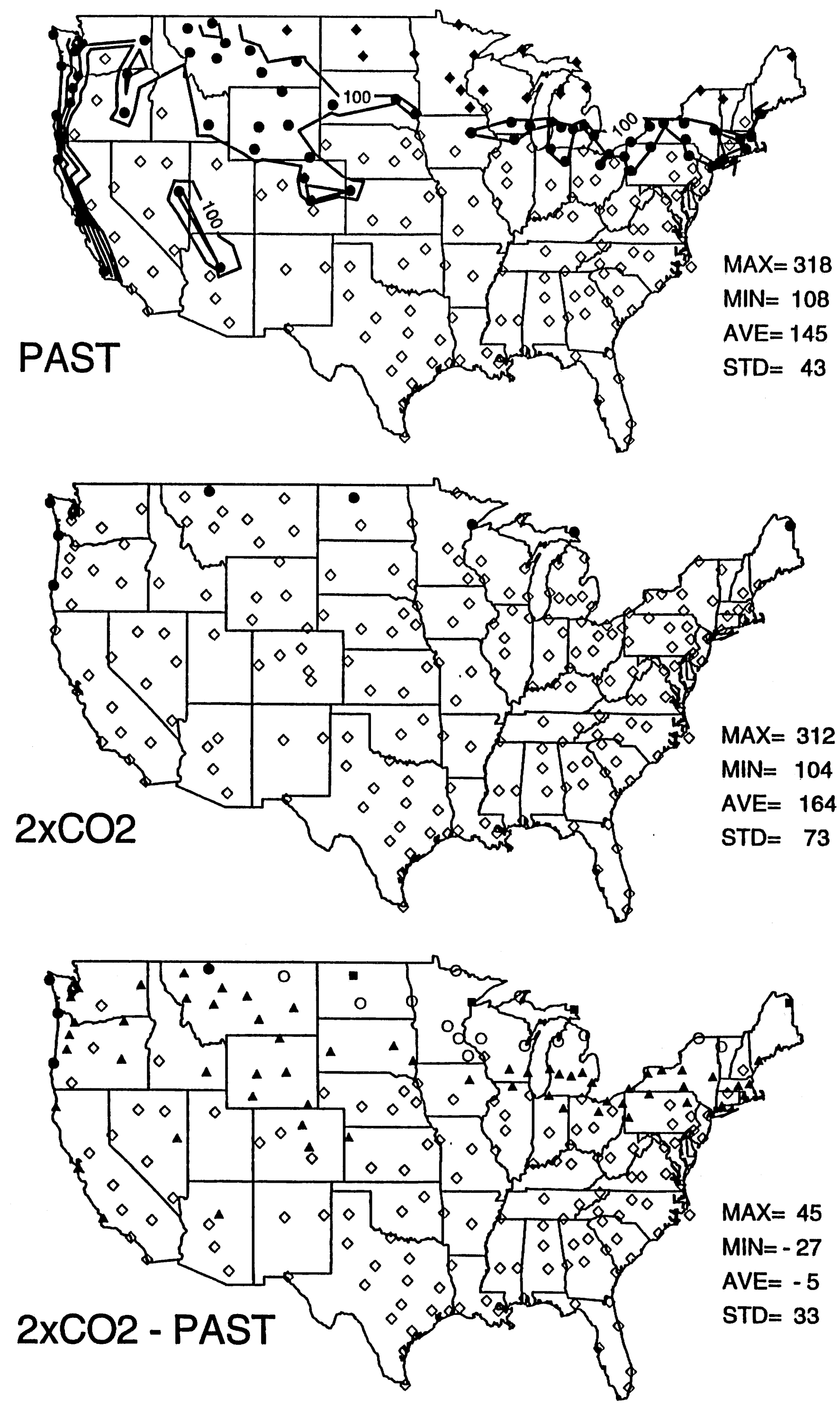

Fig. 44a Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cold-water fish in** *eutrophic, shallow, small lakes (Type 1, A_s=0.2 km²)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

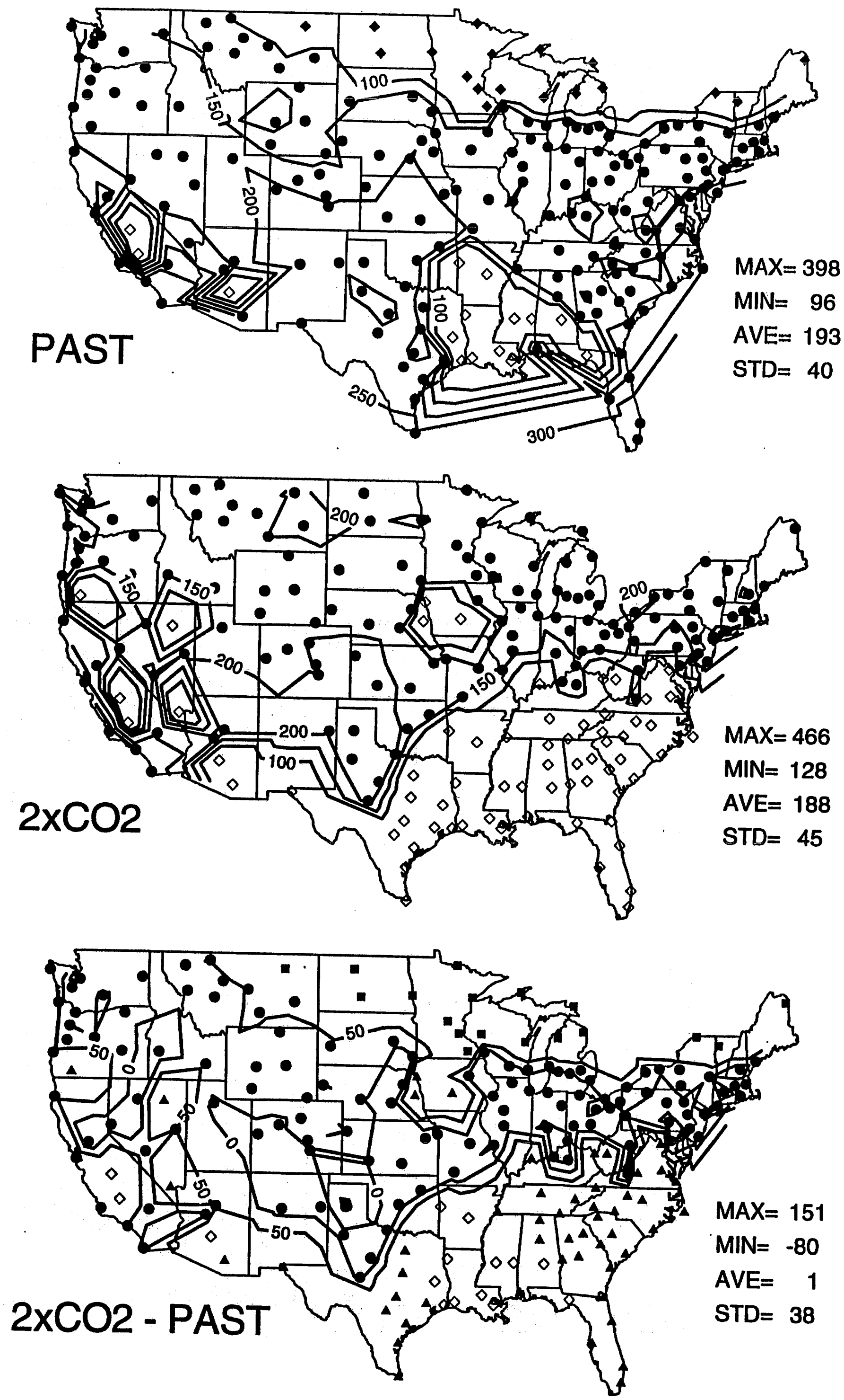

Fig. 44b Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cool-water fish in** *eutrophic, shallow, small lakes (Type 1,* $A_s=0.2\ km^2$*)* under past (1962-1979)(top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

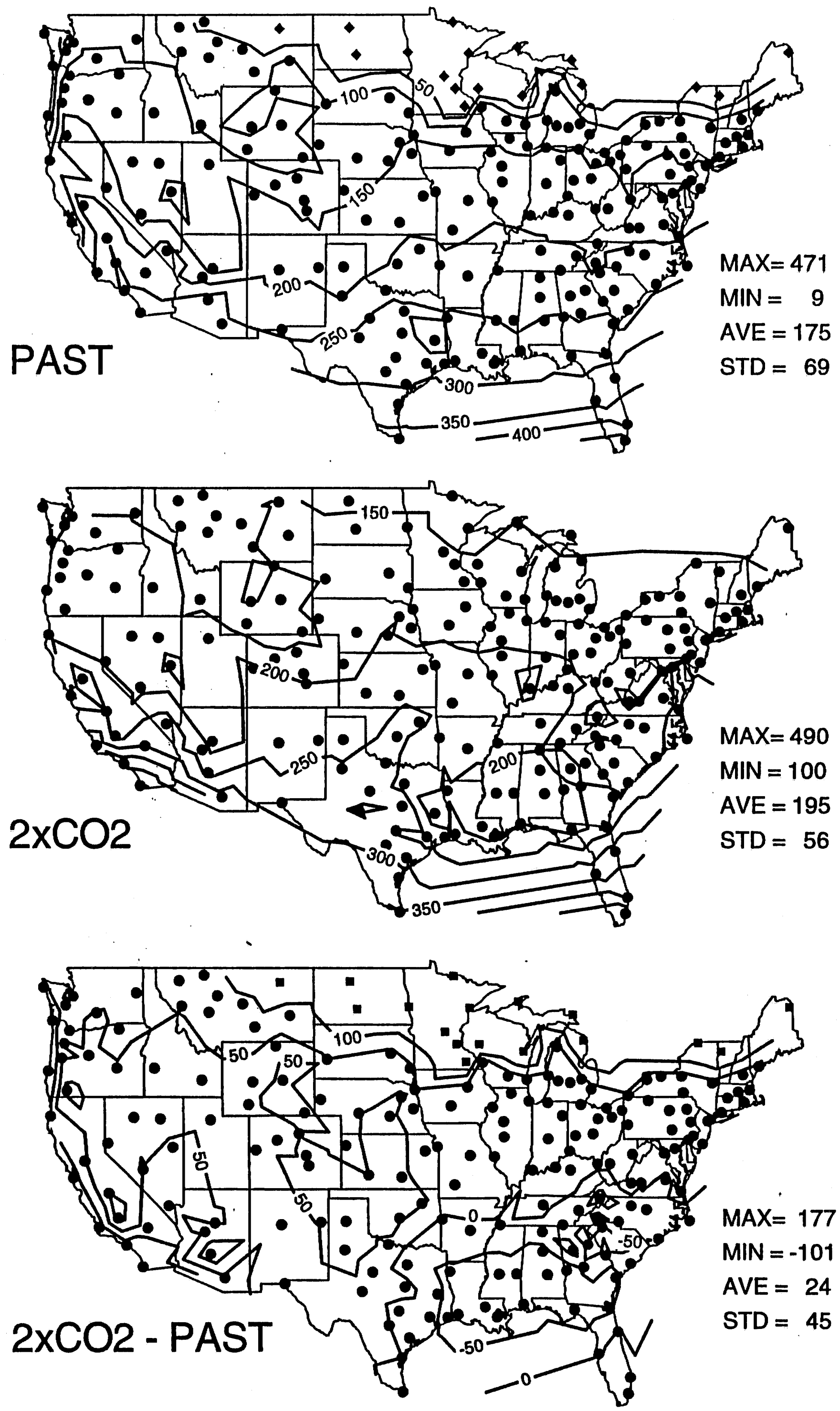

Fig. 44c Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **warmwater fish in** *eutrophic, shallow, small lakes (Type 1, $A_s=0.2\ km^2$)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

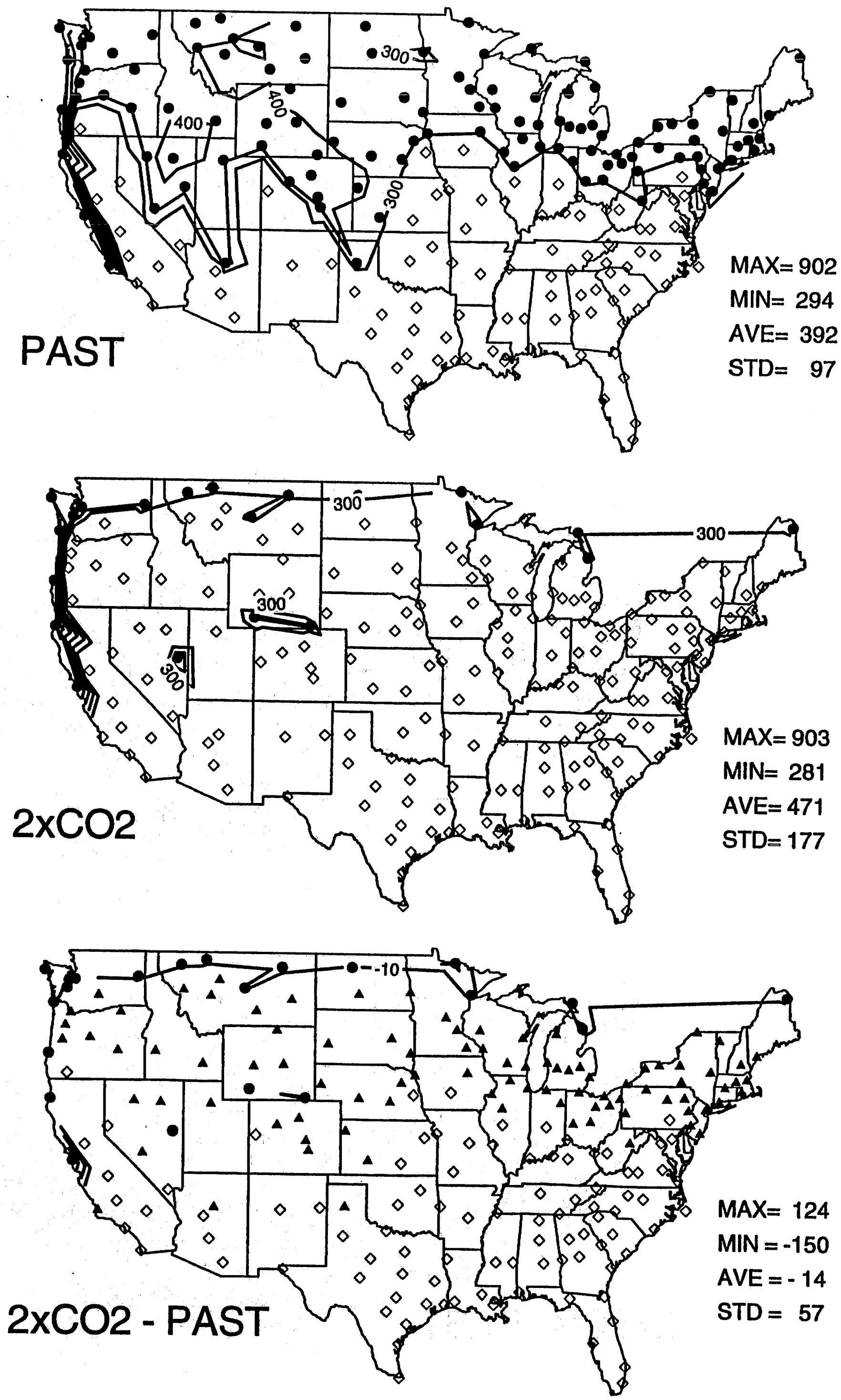

Fig. 45a Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cold-water fish in** *oligotrophic, medium-depth and -size lakes (Type 15,* A_s*=1.7km*^{2}*)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

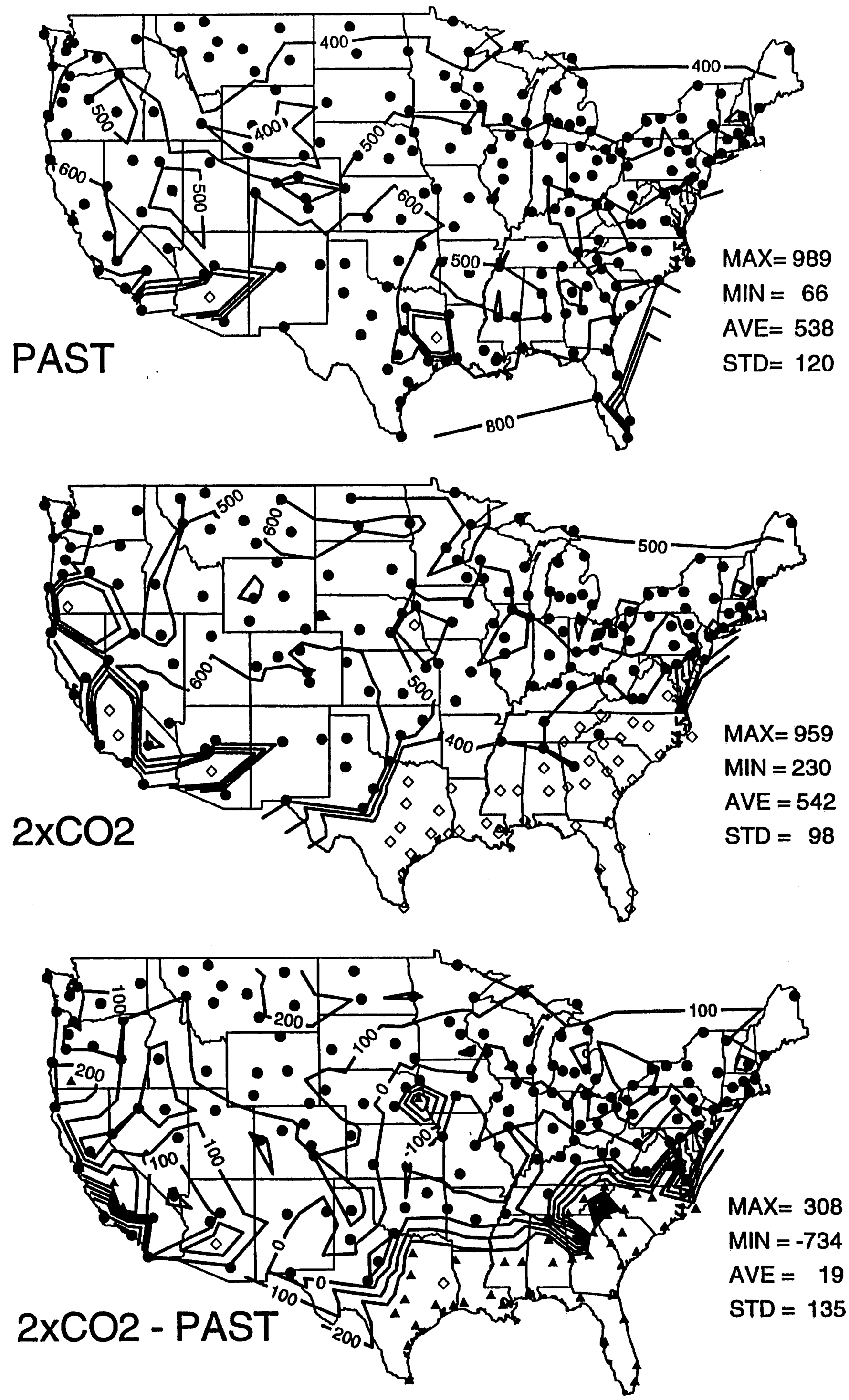

Fig. 45b Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cool-water fish in** *oligotrophic, medium-depth and -size lakes (Type 15, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

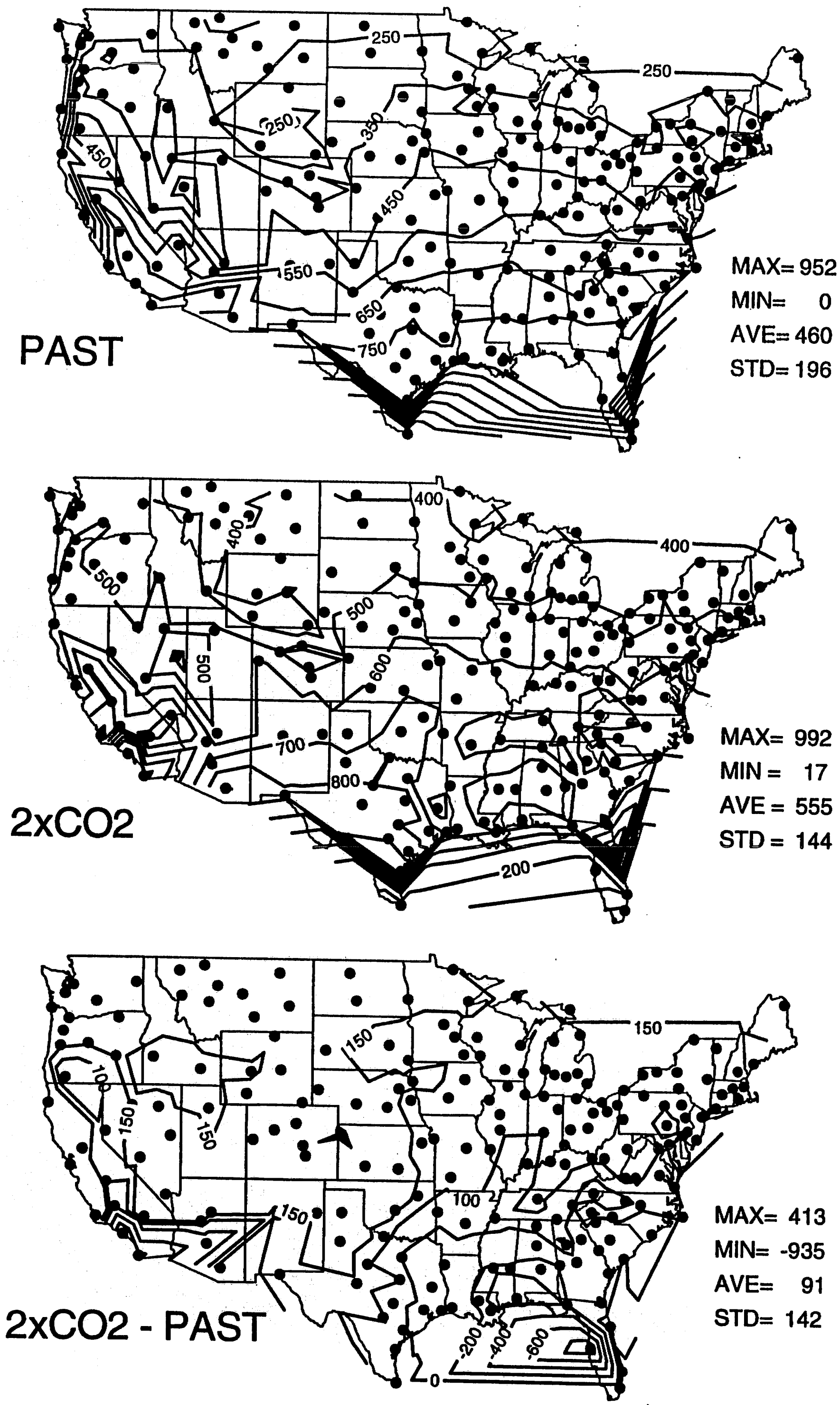

Fig. 45c Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **warmwater fish in** *oligotrophic, medium-depth and -size lakes (Type 15,* A_s*=1.7km²)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

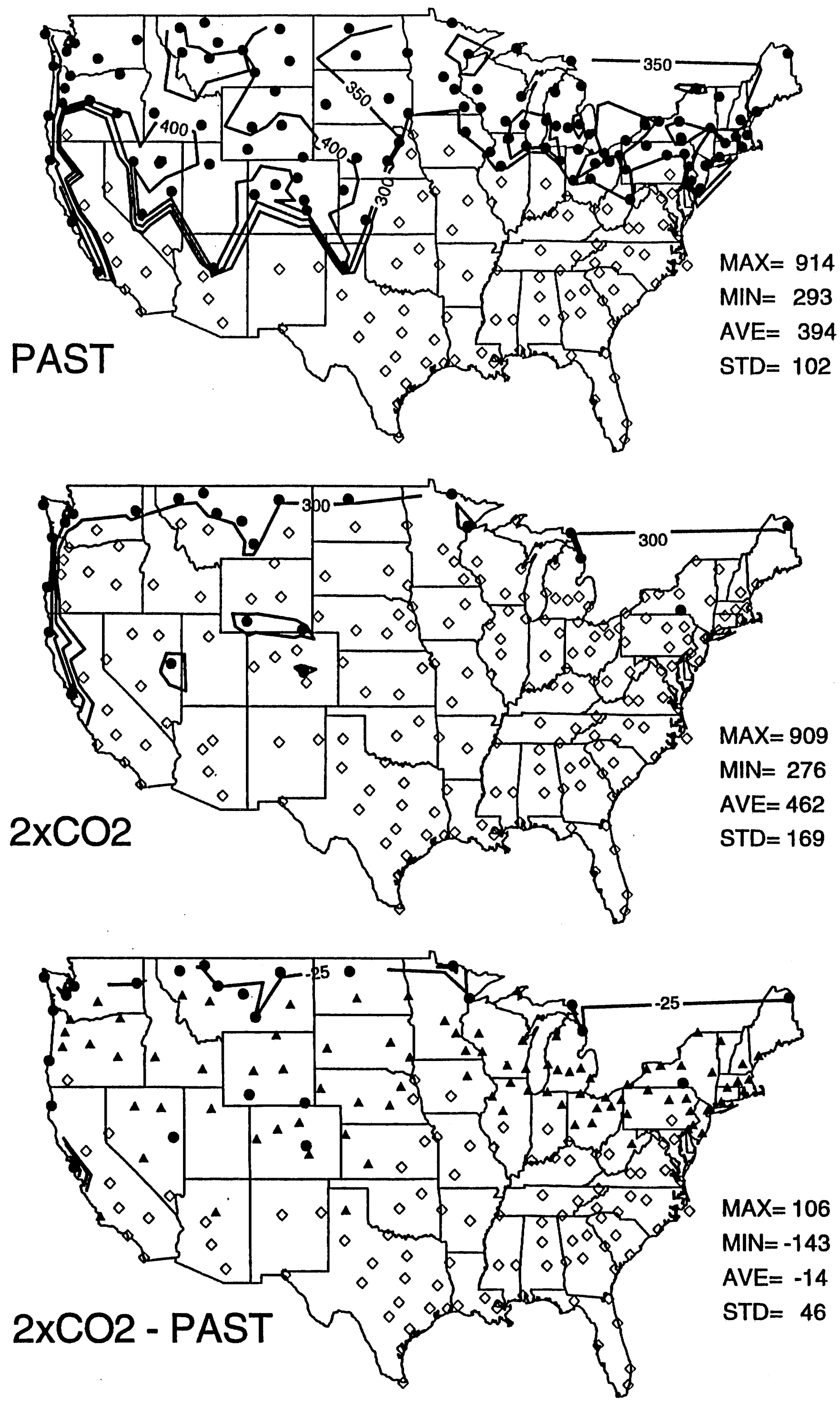

Fig. 46a Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cold-water fish in** *eutrophic, medium-depth and -size lakes (Type 13, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

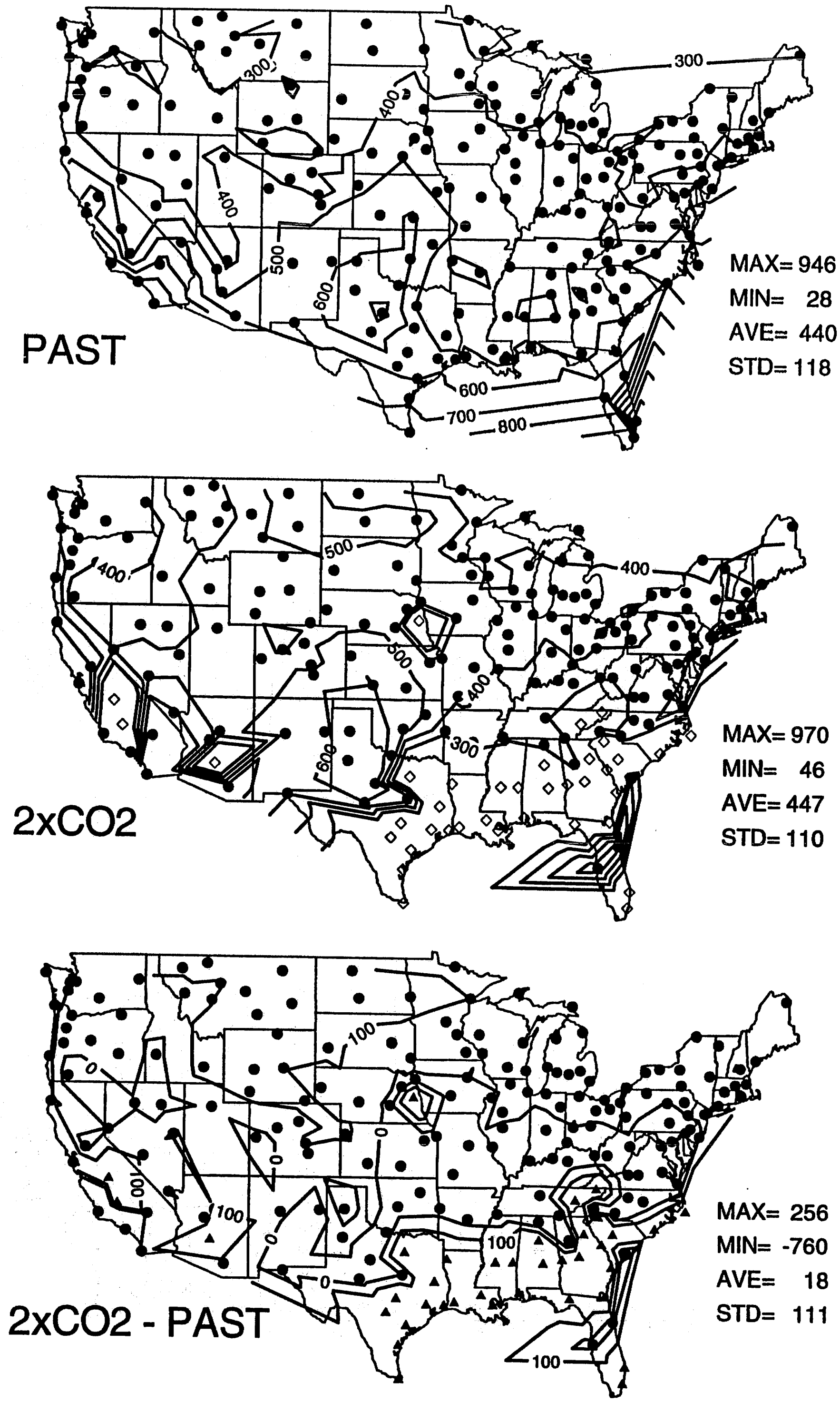

Fig. 46b Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cool-water fish in** *eutrophic, medium-depth and -size lakes (Type 13,* A_s*=1.7km²)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

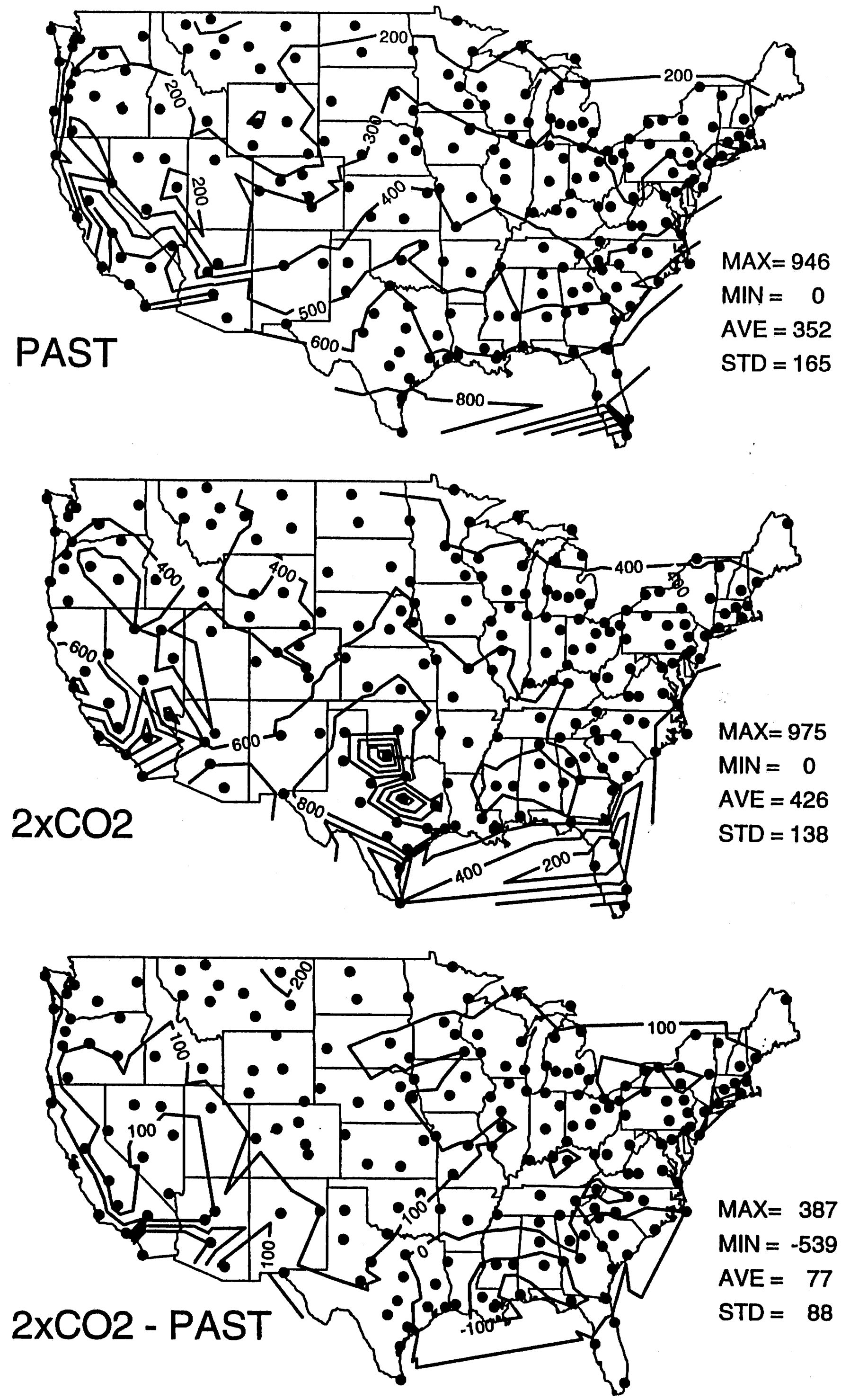

Fig. 46c Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **warmwater fish in** *eutrophic, medium-depth and -size lakes (Type 13, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

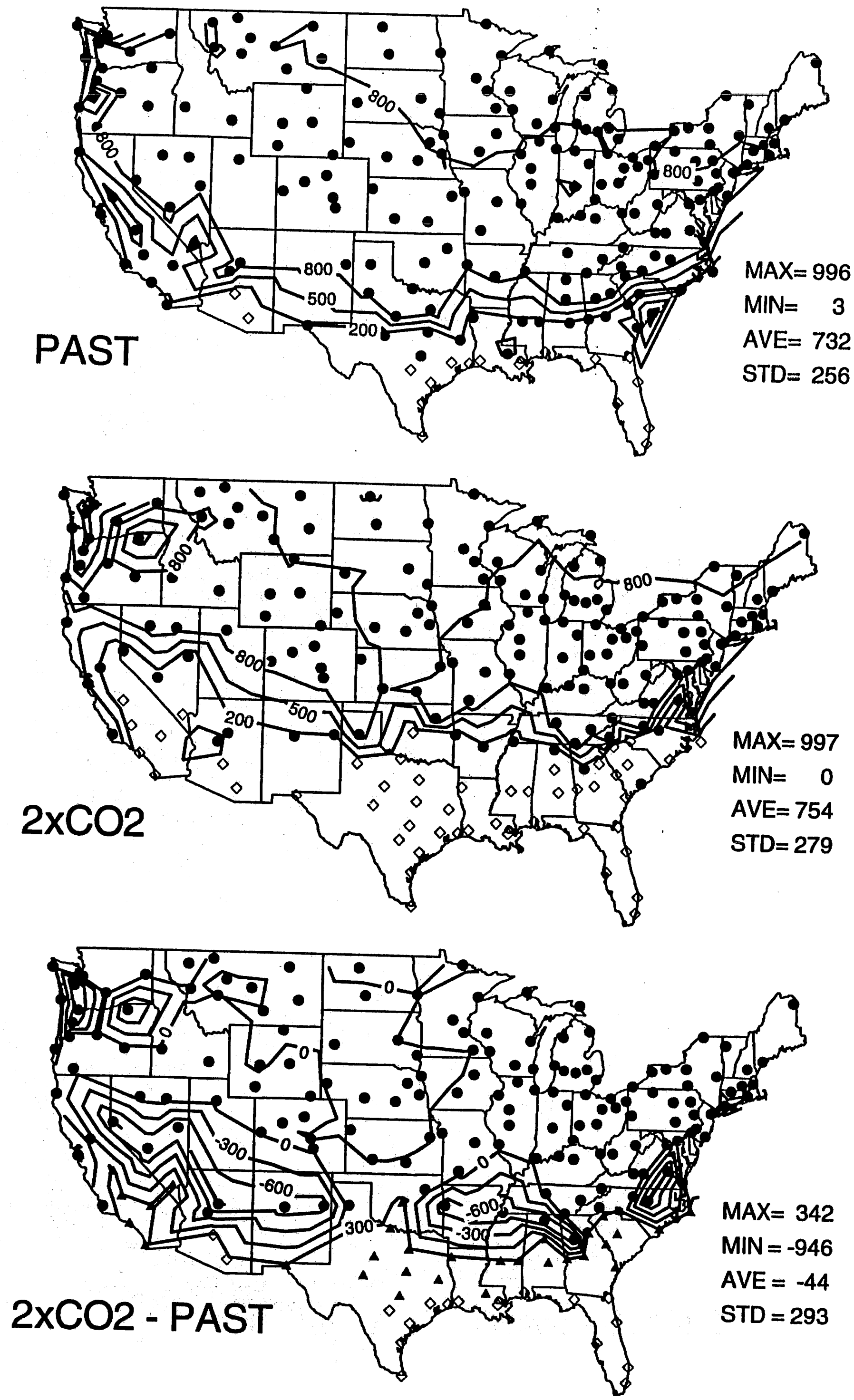

Fig. 47a Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cold-water fish in** *oligotrophic, deep, medium-size lakes (Type 24, A_s=1.7km^2)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

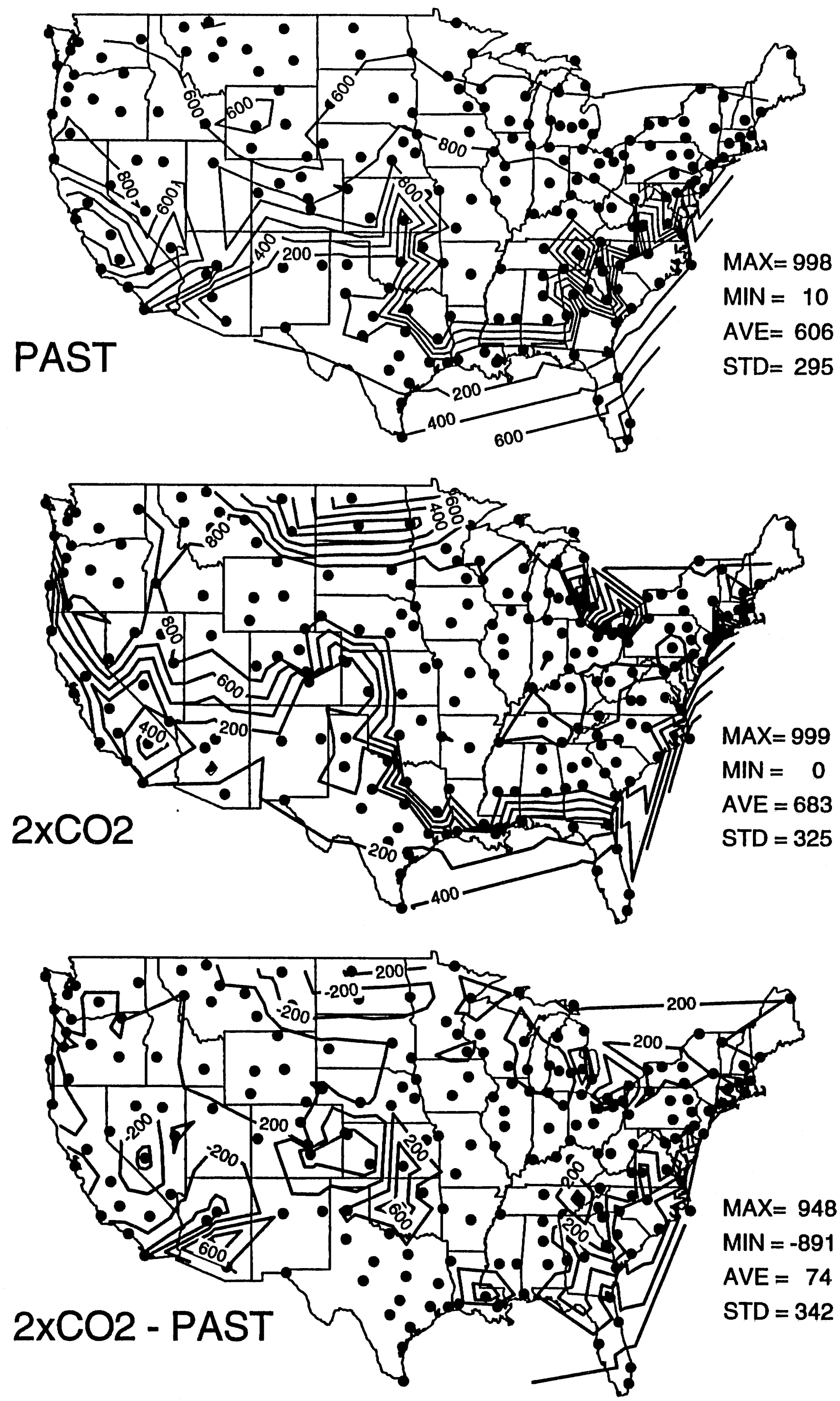

Fig. 47b Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cool-water fish in** *oligotrophic, deep, medium-size lakes (Type 24,* A_s*=1.7km²)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

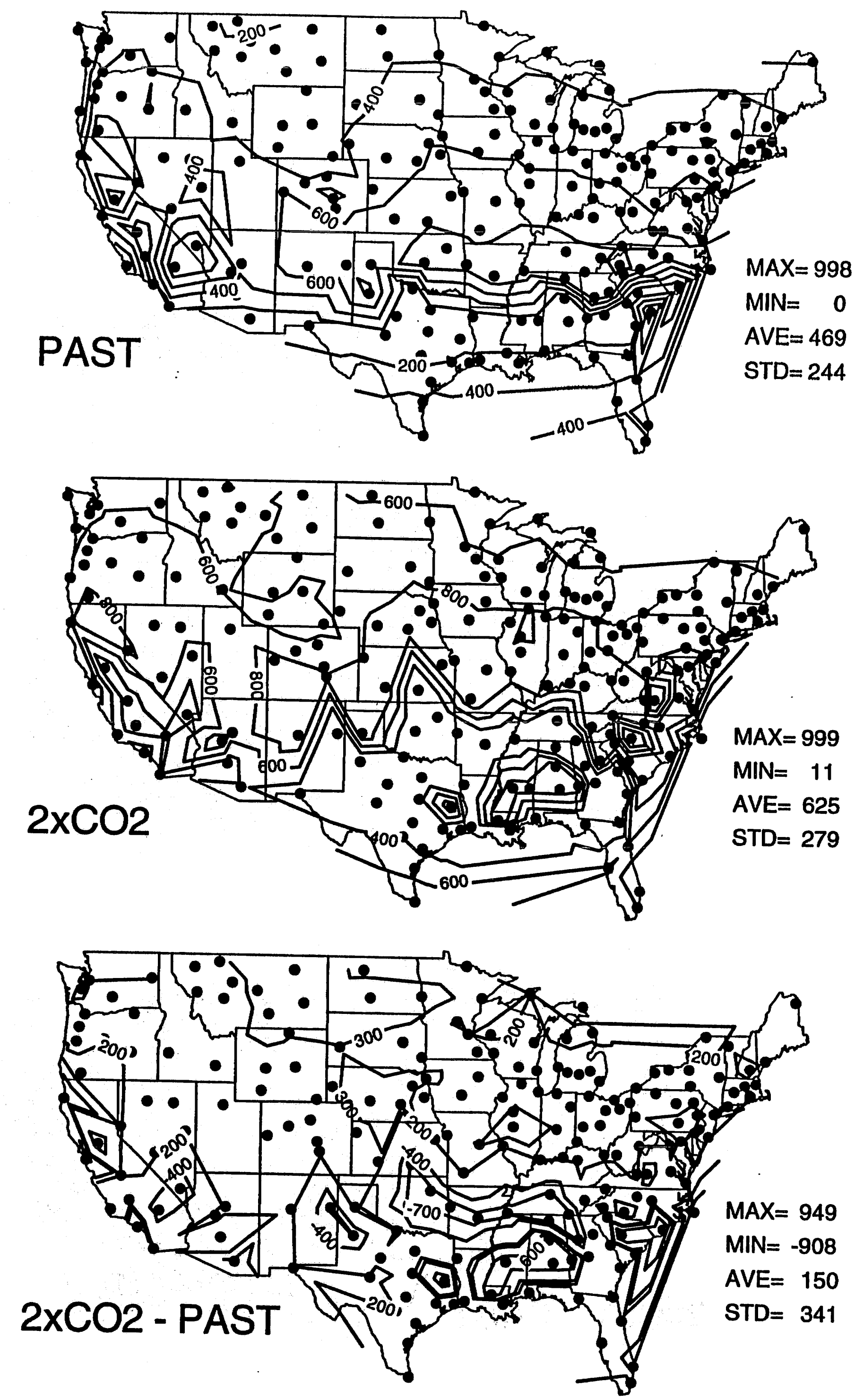

Fig. 47c Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **warmwater fish in** *oligotrophic, deep, medium-size lakes (Type 24, A_s=1.7km^2)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

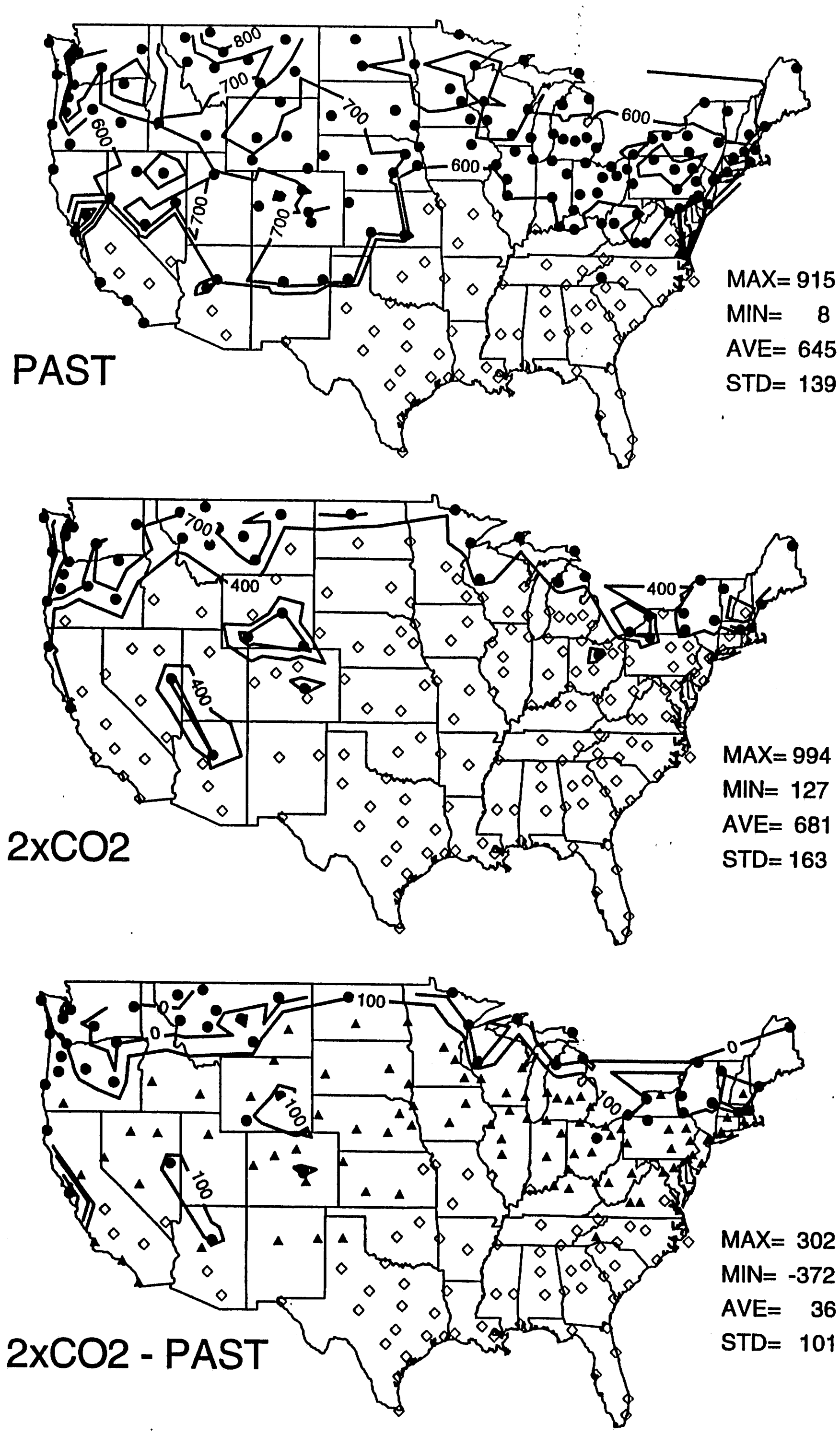

Fig. 48a Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cold-water fish in** *eutrophic, deep, medium-size lakes (Type 22, $A_s=1.7km^2$)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

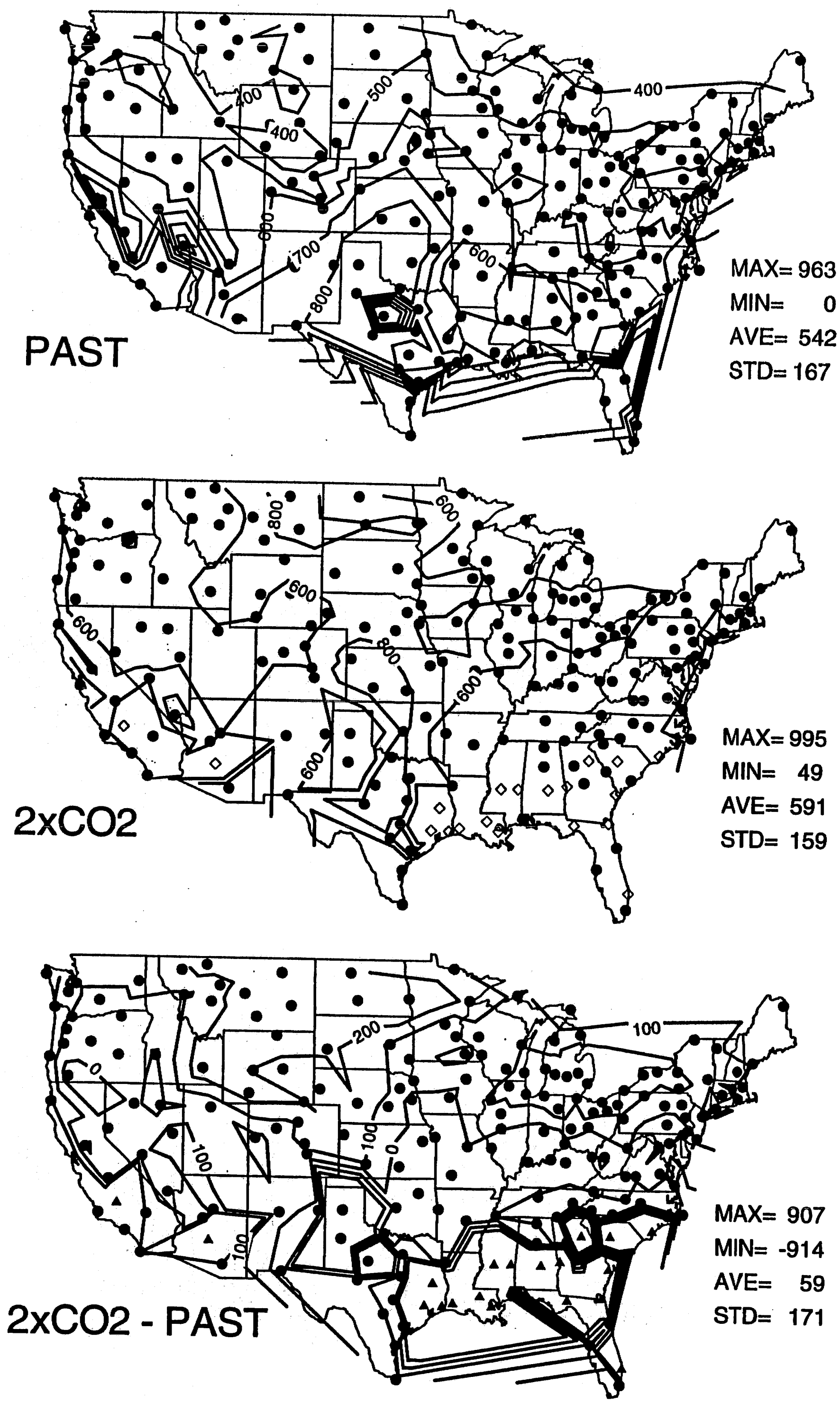

Fig. 48b Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **cool-water fish in** *eutrophic, deep, medium-size lakes (Type 22, A_s=1.7km²)* under past (1962-1979) (top) and projected 2xCO_2 (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

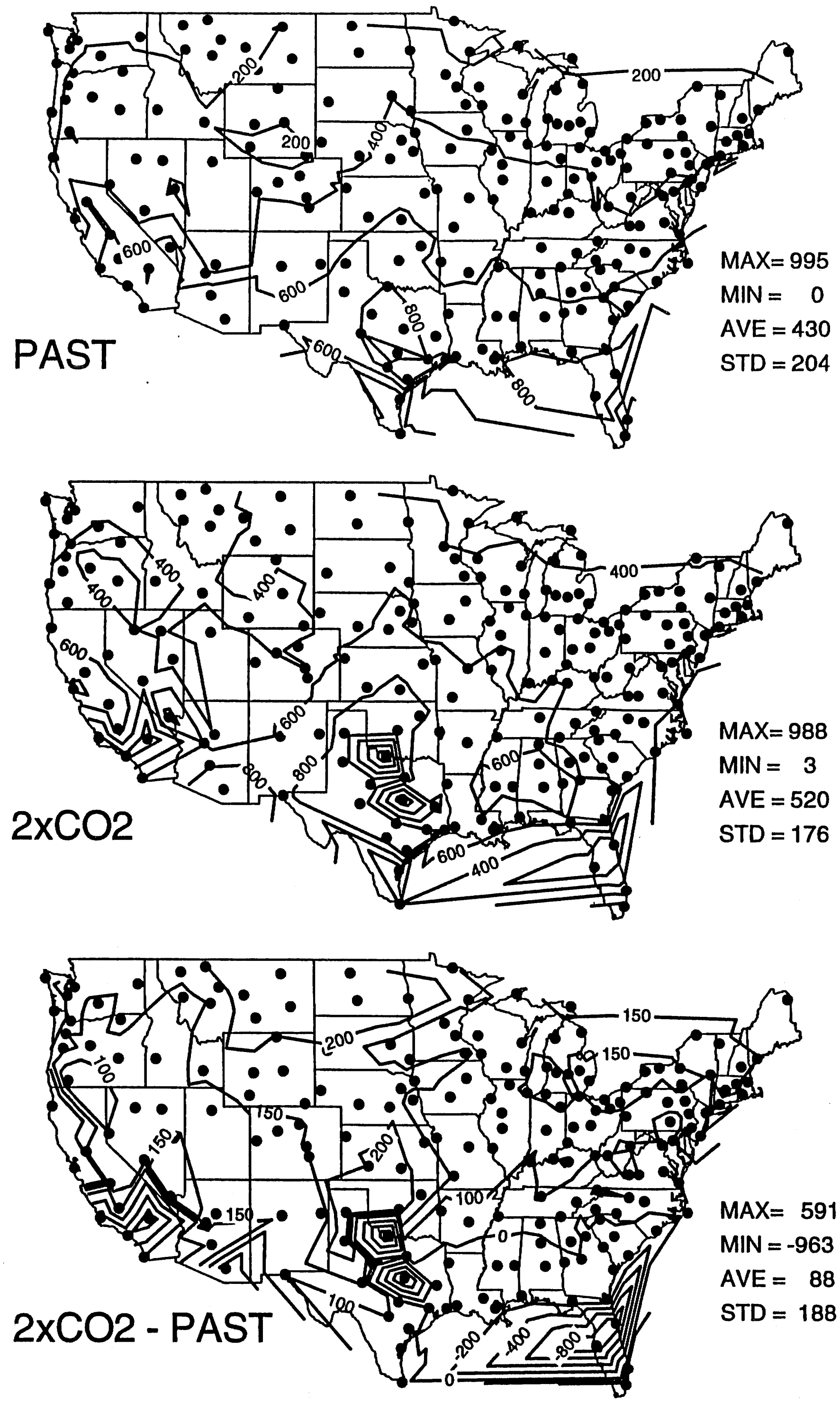

Fig. 48c Simulated, time integrated and **normalized good-growth habitat volumes (m-days)** of **warmwater fish in** *eutrophic, deep, medium-size lakes (Type 22,* $A_s=1.7km^2$*)* under past (1962-1979) (top) and projected $2xCO_2$ (middle) climate conditions; differences between projected and past climate scenarios (bottom). Symbols used are defined in Table 18.

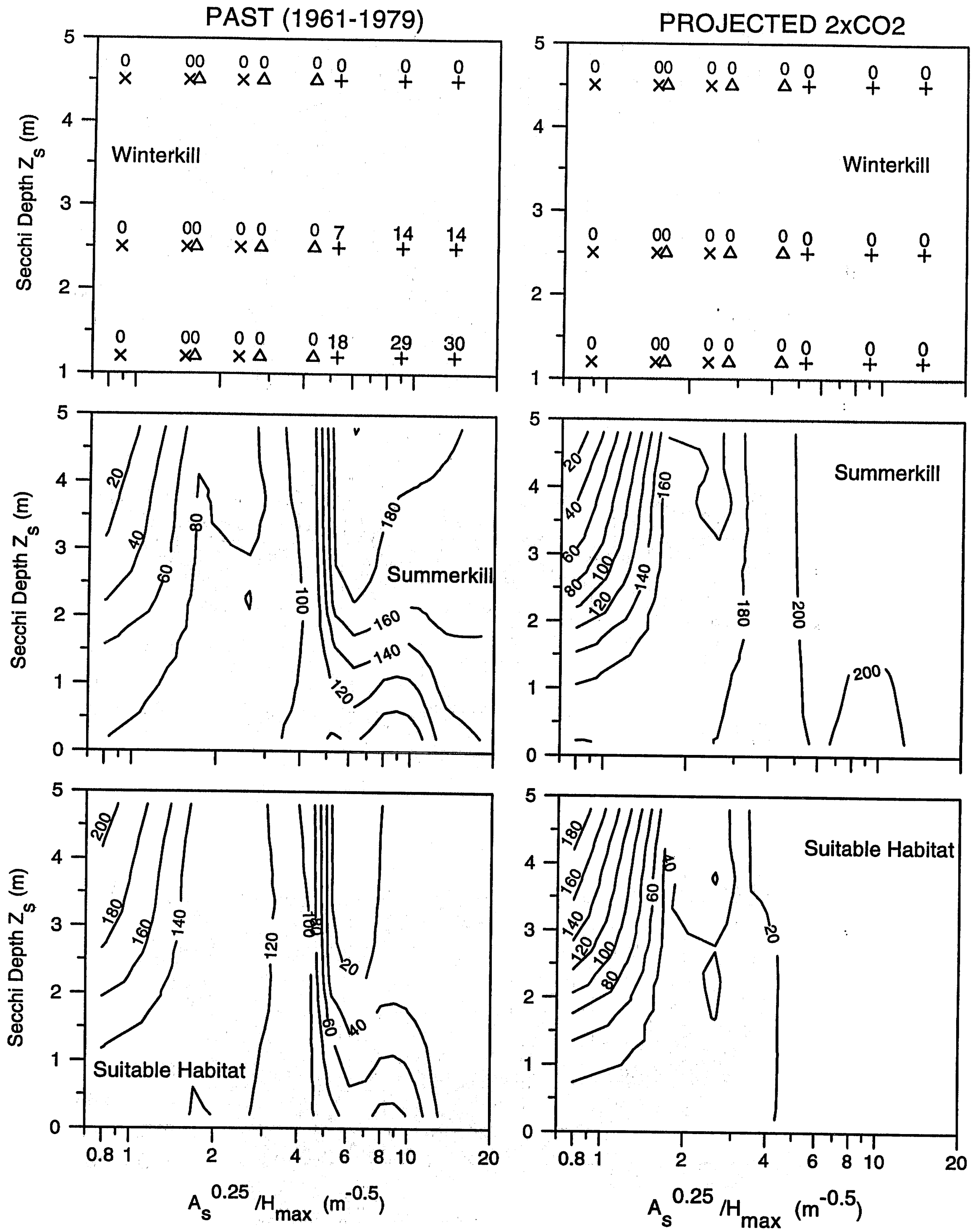

Fig. 49a Number of locations in the contiguous U.S. (out of 209 investigated) where simulated lakes have winterkill (top), summerkill (middle) and suitable habitat (bottom) for **cold-water fish** under **past** (1962-1979) (left) and **projected 2xCO₂** (right) climate scenarios, plotted as isopleths or crosses against two lake parameters.

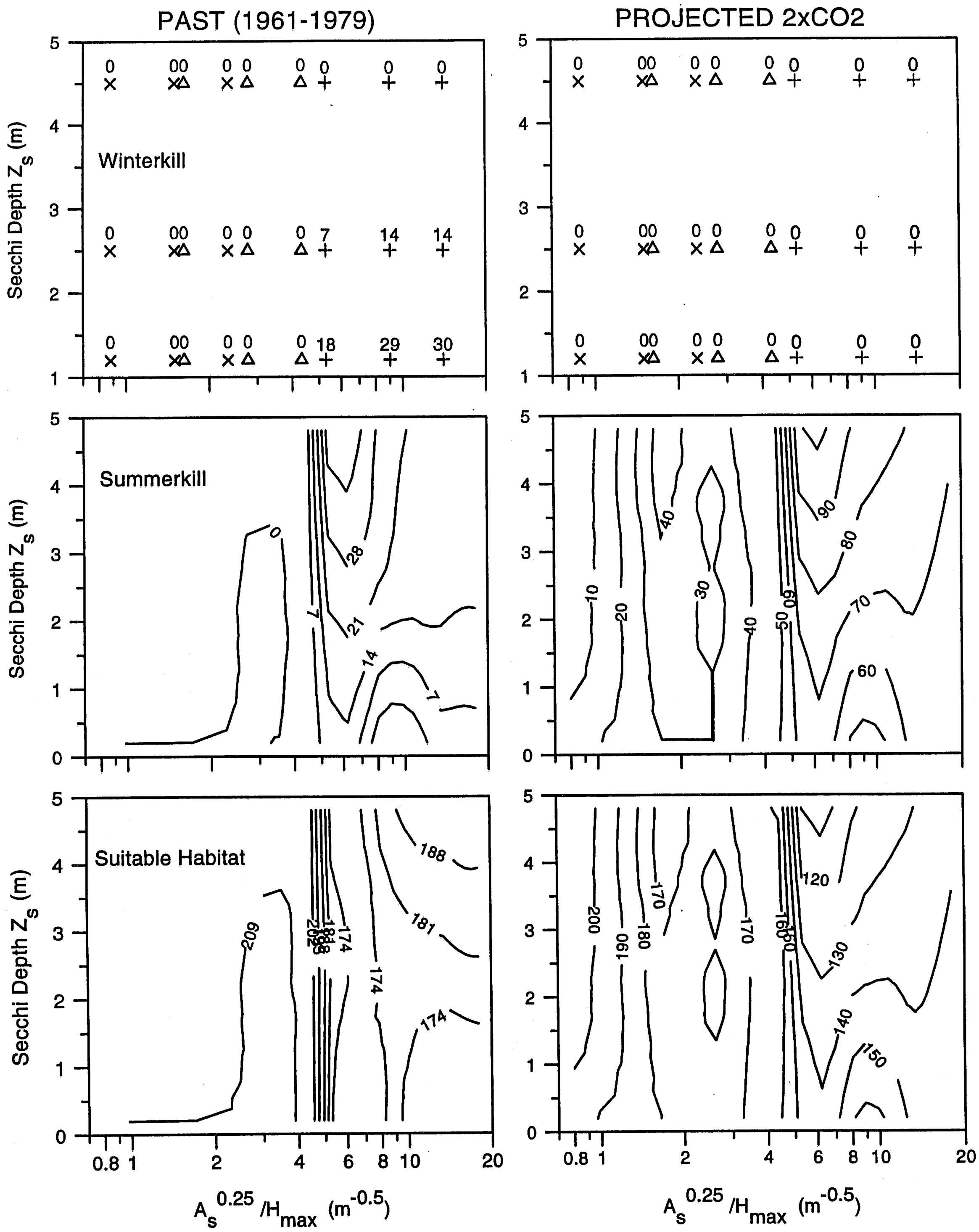

Fig. 49b Number of locations in the contiguous U.S. (out of 209 investigated) where simulated lakes have winterkill (top), summerkill (middle) and suitable habitat (bottom) for **cool-water fish** under **past** (1962-1979) (left) and **projected 2xCO_2** (right) climate scenarios, plotted as isopleths or crosses against two lake parameters.

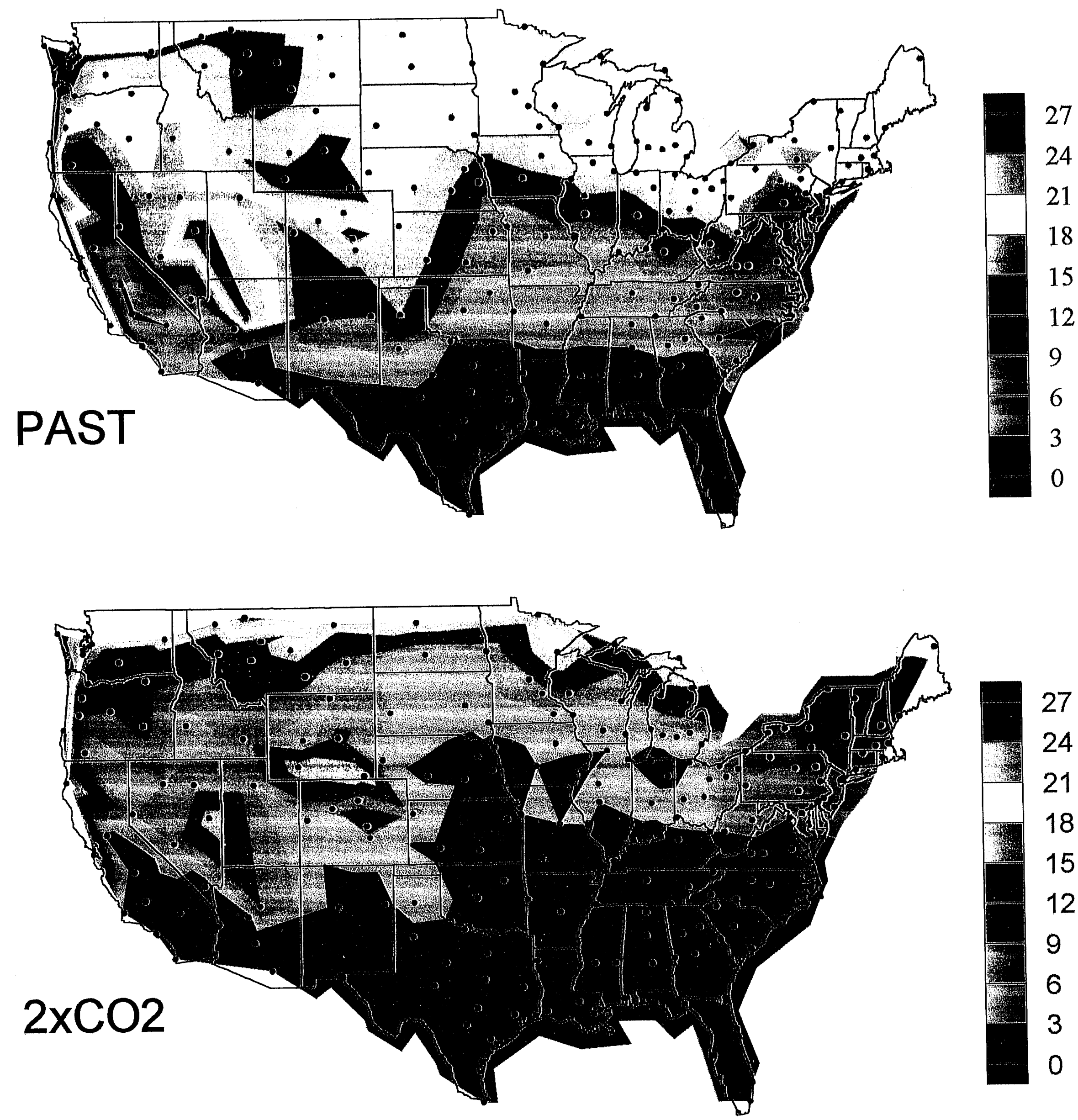

Fig. 50a Simulated number of lake types (maximum = 27 lake types) with suitable habitat for **cold-water fish** in the contiguous U.S. under past (top) and projected **2xCO_2** (bottom) climate scenarios.

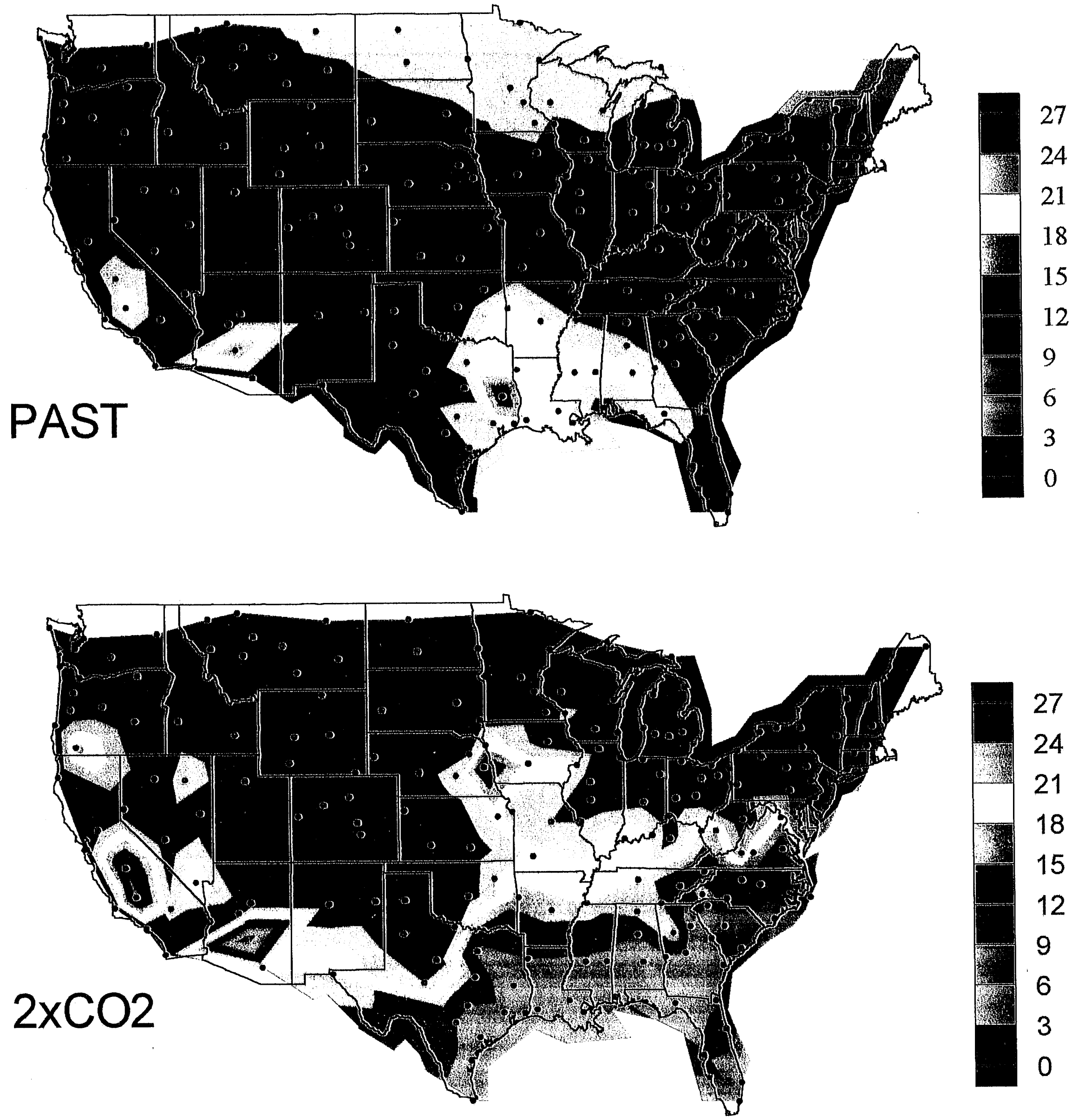

Fig. 50b Simulated number of lake types (maximum = 27 lake types) with suitable habitat for **cool-water fish** in the contiguous U.S. under past (top) and projected **$2xCO_2$** (bottom) climate scenarios.

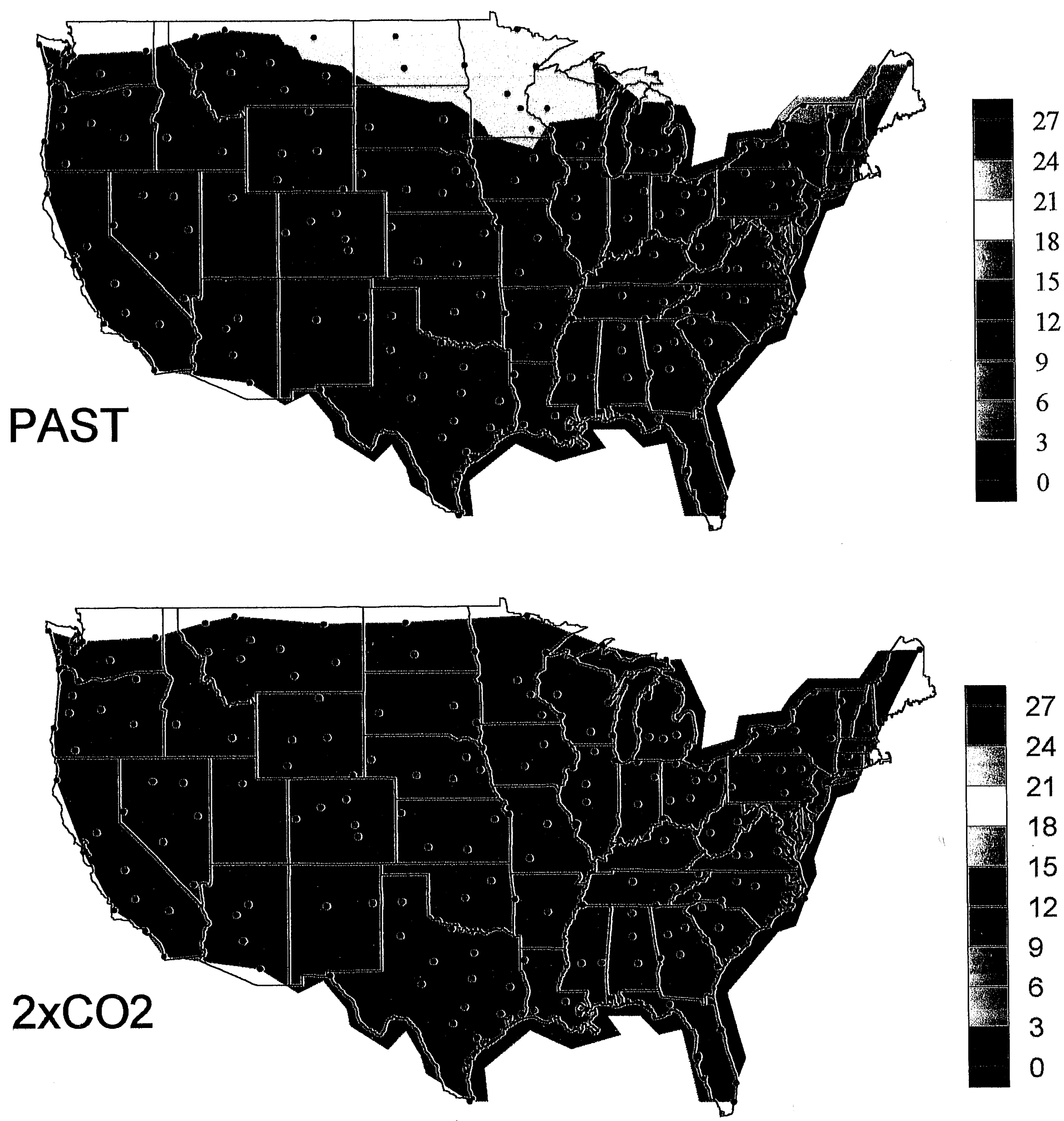

Fig. 50c Simulated number of lake types (maximum = 27 lake types) with suitable habitat for **warmwater fish** in the contiguous U.S. under past (top) and projected **$2xCO_2$** (bottom) climate scenarios.

APPENDIX

Appendix. Weather Stations Used.

State	Station Name	Latitude		Longitude		Elevation
		°N	"	°W	"	(m)
Washington	Olympia	46	58	122	54	61.0
Washington	Quillayute	47	57	124	33	55.0
Washington	Seattle	47	27	122	18	122.0
Washington	Spokane	47	38	117	32	721.0
Washington	Yakima	46	34	120	32	325.0
Montana	Billings	45	48	108	32	1088.0
Montana	Cut Bank	48	36	112	22	1170.0
Montana	Glasgow	48	13	106	37	700.0
Montana	Great Falls	47	29	111	22	1116.0
Montana	Helena	46	36	112	0	1188.0
Montana	Kalispell	48	18	114	16	904.0
Montana	Lewistown	47	3	109	27	1264.0
Montana	Miles City	46	26	105	52	803.0
Montana	Missoula	46	55	114	5	972.0
North Dakota	Bismarck	46	46	100	45	502.0
North Dakota	Fargo	46	54	96	48	274.0
North Dakota	Minot	48	16	101	17	522.0
Minnesota	Duluth	46	50	92	11	432.0
Minnesota	International Falls	48	34	93	23	361.0
Minnesota	Minneapolis	44	53	93	13	255.0
Minnesota	Rochester	43	55	92	30	402.0
Minnesota	Saint Cloud	45	33	94	4	313.0
Wisconsin	Eau Claire	44	52	91	29	273.0
Wisconsin	Green Bay	44	29	88	8	214.0
Wisconsin	La Crosse	43	52	91	15	205.0
Wisconsin	Madison	43	8	89	20	262.0
Wisconsin	Milwaukee	42	57	87	54	211.0
Michigan	Alpena	45	4	83	34	210.0
Michigan	Detroit	42	25	83	1	191.0
Michigan	Flint	42	58	83	44	233.0
Michigan	Grand Rapids	42	53	85	31	245.0
Michigan	Houghton	47	10	88	30	329.0
Michigan	Lansing	42	47	84	36	256.0
Michigan	Muskegon	43	10	86	15	191.0
Michigan	Sault St. Marie	46	28	84	22	221.0
Michigan	Traverse City	44	44	85	35	192.0
New York	Albany	42	45	73	48	89.0
New York	Binghamton	42	13	75	59	499.0
New York	Buffalo	42	56	78	44	215.0
New York	New York City	40	47	73	58	57.0
New York	Rochester	43	7	77	40	169.0
New York	Syracuse	43	7	76	7	124.0

Appendix. Weather Stations Used (Continued).

State	Station Name	Latitude		Longitude		Elevation
		°N	"	°W	"	(m)
New York	Massena	44	56	74	51	63.0
Connecticut	Bridgeport	41	10	73	8	2.0
Connecticut	Hartford	41	56	72	41	55.0
Massachusetts	Boston	42	22	71	2	5.0
Massachusetts	Worchester	42	16	71	52	301.0
Rhode Island	Providence	41	44	71	26	19.0
Vermont	Burlington	44	28	73	9	104.0
New Hampshire	Concord	43	12	71	30	105.0
Maine	Caribou	46	52	68	1	190.0
Maine	Portland	43	39	70	19	19.0
Oregon	Astoria	46	9	123	53	7.0
Oregon	Eugene	44	7	123	13	109.0
Oregon	Medford	42	22	122	52	396.0
Oregon	Pendleton	45	41	118	51	456.0
Oregon	Portland	45	36	122	36	12.0
Oregon	Salem	44	55	123	1	61.0
Oregon	Burns	43	35	119	3	1271.0
Oregon	North Bend	43	25	124	15	5.0
Oregon	Redmond	44	16	121	9	940.0
Idaho	Boise	43	34	116	13	874.0
Idaho	Pocatello	42	55	112	36	1365.0
Wyoming	Casper	42	55	106	28	1612.0
Wyoming	Cheyenne	41	9	104	49	1872.0
Wyoming	Lander	42	49	108	44	1696.0
Wyoming	Sheridan	44	46	106	58	1209.0
Wyoming	Rock Springs	41	36	109	4	2056.0
South Dakota	Huron	44	23	98	13	393.0
South Dakota	Rapid City	44	3	103	4	966.0
South Dakota	Sioux Falls	43	34	96	44	435.0
Iowa	Des Moines	41	32	93	39	294.0
Iowa	Sioux City	42	24	96	23	336.0
Iowa	Waterloo	42	33	92	24	265.0
Illinois	Chicago	41	47	87	45	190.0
Illinois	Moline	41	27	90	31	181.0
Illinois	Peoria	40	40	89	41	199.0
Illinois	Rockford	42	12	89	6	221.0
Illinois	Springfield	39	50	89	40	187.0
Indiana	Evansville	38	2	87	31	118.0
Indiana	Fort Wayne	41	0	85	12	252.0
Indiana	Indianapolis	39	44	86	17	246.0
Indiana	South Bend	41	42	86	19	236.0
Ohio	Akron	40	55	81	26	377.0

Appendix. Weather Stations Used (Continued).

State	Station Name	Latitude		Longitude		Elevation
		°N	"	°W	"	(m)
Ohio	Cleveland	41	24	81	51	245.0
Ohio	Columbus	40	0	82	53	254.0
Ohio	Dayton	39	54	84	13	306.0
Ohio	Mansfield	40	49	82	31	395.0
Ohio	Toledo	41	36	83	48	211.0
Ohio	Youngstown	41	16	80	40	361.0
Pennsylvania	Allentown	40	39	75	26	117.0
Pennsylvania	Erie	42	5	80	11	225.0
Pennsylvania	Harrisburg	40	13	76	51	106.0
Pennsylvania	Philadelphia	39	53	75	15	9.0
Pennsylvania	Pittsburgh	40	30	80	13	373.0
Pennsylvania	Wilkes-Barre	41	20	75	44	289.0
Pennsylvania	Williamsport	41	16	77	3	243.0
Pennsylvania	Bradford	41	48	78	38	600.0
New Jersey	Atlantic City	39	27	74	34	20.0
New Jersey	Newwark	40	42	74	10	9.0
Nevada	Elko	40	50	115	47	1547.0
Nevada	Ely	39	17	114	51	1906.0
Nevada	Las Vegas	36	5	115	10	664.0
Nevada	Reno	39	30	119	47	1341.0
Nevada	Tonopah	38	4	117	8	1653.0
Nevada	Winnemcucca	40	54	117	48	1323.0
Utah	Salt Lake City	40	46	111	58	1288.0
Colorado	Boulder	40	1	105	15	1634.0
Colorado	Colorado Spring	38	49	104	43	1881.0
Colorado	Eagle	39	39	106	55	1985.0
Colorado	Grand Junction	39	7	108	32	1475.0
Colorado	Pueblo	38	17	104	31	1439.0
Nebraska	Grand Island	40	58	98	19	566.0
Nebraska	Norfolk	41	59	97	26	471.0
Nebraska	North Platte	41	8	100	41	849.0
Nebraska	Omaha	41	22	96	31	404.0
Nebraska	Scottsbluff	41	52	103	36	1206.0
Kansas	Dodge City	37	46	99	58	787.0
Kansas	Goodland	39	22	101	42	1124.0
Kansas	Topeka	39	4	95	38	270.0
Kansas	Wichita	37	39	97	25	408.0
Missouri	Columbia	38	49	92	13	270.0
Missouri	Kansas City	39	18	94	43	315.0
Missouri	Springfield	37	14	93	23	387.0
Missouri	St. Louis	38	45	90	23	172.0
Kentucky	Covington	39	4	84	40	271.0

Appendix. Weather Stations Used (Continued).

State	Station Name	Latitude		Longitude		Elevation
		°N	"	°W	"	(m)
Kentucky	Lexington	38	2	84	36	301.0
Kentucky	Louisville	38	11	85	44	149.0
West Virginia	Charleston	38	22	81	36	290.0
West Virginia	Elkins	38	53	79	51	594.0
West Virginia	Huntington	38	22	82	33	255.0
Virginia	lynchburg	37	20	79	12	279.0
Virginia	Norfolk	36	54	76	12	9.0
Virginia	Richmond	37	30	77	20	50.0
Virginia	Roanoke	37	19	79	58	358.0
Virginia	Sterling	38	57	77	27	82.0
Delaware	Wilmington	39	40	75	36	24.0
California	Arcata	40	59	124	6	69.0
California	Bakerfield	35	25	119	3	150.0
California	Daggett	34	52	116	47	588.0
California	Persno	36	46	119	43	100.0
California	Los Angeles	33	56	118	24	32.0
California	Sacramento	38	31	121	30	8.0
California	San Diego	32	44	117	10	9.0
California	San Francisco	37	37	122	23	5.0
California	Santa Maria	34	54	120	27	72.0
Arizona	Flagstaff	35	8	111	40	2135.0
Arizona	Phoenix	33	26	112	1	339.0
Arizona	Prescott	34	39	112	26	1531.0
Arizona	Tucson	32	7	110	56	779.0
New Mexico	Albuquerque	35	3	106	37	1619.0
New Mexico	Tucumcari	35	11	103	36	1231.0
Texas	Abliene	32	26	99	41	534.0
Texas	Amarillo	35	14	101	42	1098.0
Texas	Austin	30	18	97	42	189.0
Texas	Brownsville	25	54	97	26	6.0
Texas	Corpus Christi	27	46	97	30	13.0
Texas	El Paso	31	48	106	24	1194.0
Texas	Fort Worth	32	50	97	3	164.0
Texas	Houston	29	59	95	22	33.0
Texas	Lubbock	33	39	101	49	988.0
Texas	Lufkin	31	14	94	45	96.0
Texas	Port Authur	29	57	94	1	7.0
Texas	San Angelo	31	22	100	30	582.0
Texas	San Antonio	29	32	98	28	242.0
Texas	Victoria	28	51	96	55	32.0
Texas	Waco	31	37	97	13	155.0

Appendix. Weather Stations Used (Continued).

State	Station Name	Latitude		Longitude		Elevation
		°N	"	°W	"	(m)
Texas	Wichita Falls	33	58	98	29	314.0
Arkansas	Fort Smith	35	20	94	22	141.0
Arkansas	Little Rock	34	44	92	14	81.0
Louisiana	Baton Rouge	30	32	91	9	23.0
Louisiana	Lake Charles	30	7	93	13	3.0
Louisiana	New Orleans	29	59	90	15	3.0
Louisiana	Shreveport	32	28	93	49	79.0
Okalahoma	Oklahoma City	35	24	97	36	397.0
Okalahoma	Tulsa	36	12	95	54	206.0
Mississippi	Jackson	32	19	90	5	101.0
Mississippi	Meridain	32	20	88	45	94.0
Tennessee	Bristol	36	29	82	24	459.0
Tennessee	Chattanooga	35	2	85	12	210.0
Tennessee	Knoxville	35	49	83	59	299.0
Tennessee	Memphis	35	3	89	59	87.0
Tennessee	Nashville	36	7	86	41	180.0
Alabama	Birmingham	33	34	86	45	192.0
Alabama	Huntsville	34	39	86	46	190.0
Alabama	Mobile	30	41	88	15	67.0
Alabama	Montgomery	32	18	86	24	62.0
Georgia	Athens	33	57	83	19	244.0
Georgia	Atlanta	33	39	84	26	315.0
Georgia	Augusta	33	22	81	58	45.0
Georgia	Columbus	32	31	84	57	136.0
Georgia	Macon	32	42	83	39	110.0
Georgia	Savannah	32	8	81	12	16.0
North Carolina	Asheville	35	26	82	32	661.0
North Carolina	Cape Hatteras	35	16	75	33	2.0
North Carolina	Charlotte	35	13	80	56	234.0
North Carolina	Greensboro	36	5	79	57	270.0
North Carolina	Raleigh	35	52	78	47	134.0
North Carolina	Wilmington	34	16	77	54	9.0
South Carolina	Charleston	32	54	80	2	12.0
South Carolina	Columbia	33	57	81	7	69.0
South Carolina	Greenville	34	54	82	13	296.0
Florida	Daytona Beach	29	11	81	3	12.0
Florida	Jacksonville	30	30	81	42	9.0
Florida	Miami	25	48	80	16	2.0
Florida	Tallahassee	30	23	84	22	21.0
Florida	Tampa	27	58	82	32	3.0
Florida	West Palm Beach	26	41	80	6	6.0
Maryland	Baltimore	39	11	76	40	47.0