Final Report for Texas Temperature and Dissolved Oxygen Criteria Development Support Project

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LIST OF ACRONYMS

CAP	Corrective Action Plan
CTM	Critical Thermal Maximum
DO	Dissolved Oxygen
EPA	United States Environmental Protection Agency
JMP SAS®	JMP Statistical Analysis Software
LT50	Lethal Temperature to 50% of a Population
LTi50	Time it takes for a particular temperature to be lethal to 50% of a Population
NTE	Not to exceed
PI	Principal Investigator
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
QPR	Quarterly Progress Report
QMP	Quality Management Plan
SOP	Standard Operating Procedure
SOW	Statement of Work
SSD	Species Sensitive Distribution
TCEQ	Texas Commission on Environmental Quality
T_a	Acclimation Temperature
TTI	Temperature Tolerance Interval
TTU	Texas Tech University
WQS	Water Quality Standards

EXECUTIVE SUMMARY

The Texas Commission on Environmental Quality (TCEQ) currently has temperature maxima criteria which apply to all designated segments and established temperature differentials (rise over ambient) which apply to all water bodies of the state. The TCEQ also has general presumptions in regard to dissolved oxygen criteria that apply in tidal waters. Since these standards were established, research on temperature and dissolved oxygen has occurred, and a review of this updated scientific information may provide better insight into current standards. In addition, these data may suggest whether an update to the current temperature and dissolved oxygen standards is warranted. The purpose of this contract is to address this issue, and the following objectives were identified: (1) review historical lethal and sublethal temperature data for native Texas fishes, amphibians, and aquatic invertebrates, (2) assess other states temperature standards and criteria, and (3) review historical lethal and sublethal dissolved oxygen data for native Texas fish and aquatic invertebrates in marine and tidally-influenced water bodies.

Databases were generated for the project objectives. Parts of these databases are attached to this report in printed form as appendices. The complete searchable databases will be provided in a digital format. From these databases, patterns were assessed related to temperature toxicity to endemic Texas fish, amphibians, and invertebrate species and dissolved oxygen toxicity to endemic Texas marine and estuarine fish and invertebrate species. Species sensitivity distributions (SSDs) were used to compare the same response variables across species in order to rank sensitivity among species to the stressors of interest (i.e., temperature and dissolve oxygen). The SSDs were successful in separating species based on taxonomic group and age (e.g., larval vs. juvenile vs. adult) and helped to identify certain taxa that may be sensitive to lower dissolved oxygen levels or high temperature levels. A general pattern observed for vertebrate sensitivity to temperature was that fish were more sensitive to increasing temperature than amphibians. For dissolved oxygen, a general pattern that emerged was that aquatic invertebrate species were less sensitive to low levels of dissolved oxygen compared to fish species.

Water quality standards specifically regarding temperature were evaluated for each of the fifty U.S. states. Temperature standards in the form of thresholds, differentials, and rates were assessed. States were highly variable in each approach for temperature standards and criteria. Some states used very simple universally applied thresholds or differentials while other states had intricate temperature standards that applied to multiple site-specific waterways, multiple designated uses, seasonality/temporal categories, biological criteria, and combinations of all these factors. It is anticipated that several approaches reported by states may be useful to the TCEQ regarding reassessment of differentials.

As a whole, information generated from this project on biotic responses to temperature and dissolved oxygen in combination with the assessment of approaches used in other states will assist TCEQ in assessing current temperature and dissolved oxygen standards/criteria in the state of Texas.

INTRODUCTION

Problem Statement

The Texas Commission on Environmental Quality (TCEQ) currently has temperature maxima criteria which apply to all designated segments and established temperature differentials (rise over ambient) which apply to all water bodies of the state. These differentials are based largely on the 1968 National Technical Advisory Committee's recommendations (the "Green Book") and may benefit from a review of updated scientific information. The TCEQ also has general presumptions in regard to dissolved oxygen criteria that apply in tidal waters. Recent studies funded by TCEQ have suggested that dissolved oxygen concentration may not be a major structuring factor in fish assemblages (Tolan 2011, Tolan et al. 2011), and the presumed criteria for dissolved oxygen may need to be re-evaluated. The most recent approach to developing dissolved oxygen criteria in tidal waters by the Environmental Protection Agency (EPA) is to use data on lethality and sub-lethality of location-specific aquatic organisms. The purpose of this contract is to (1) gather current and past temperature and dissolved oxygen toxicity data, especially regarding sublethal effects, (2) analyze these data to identify relationships using species sensitivity distributions (SSDs), (3) survey other states' temperature water quality standards and implementation methods, and (4) provide this information to the TCEQ for consideration when re-evaluating if current temperature differentials and dissolved oxygen presumptions remain scientifically defensible. This information could also provide helpful insight into alternate approaches that could be used to set site-specific differentials in certain regions of the state, for particular water body types, and/or receiving water bodies in Texas Pollutant Discharge Elimination System permits.

Background on Species Sensitivity Distributions

A SSD can be used to generate mean sensitivities and a range of sensitivities among species for a specific stressor (DeVries et al. 2008). SSD methodology considers the entire available data set and links a confidence interval with the predicted values (Duboudin et al. 2004). A SSD generates relative sensitivities of species by making predictions for affected and unaffected species in various scenarios (Shaw-Allen and Sutter). SSDs are mainly generated using laboratory-derived toxicity data, and it has been shown by Hose and Van den Brink (2004) and Schroer et al. (2004) that SSD curves and the potentially affected fraction (PAF) are similar to those derived from mesocosm data (Hose and Van den Brink 2004). The PAF predicts the risk to species using information from a subset of the species (Frampton et al., 2006). Most SSDs are generated for chemical stressors, but SSDs have also been applied to non-chemical stressors such as temperature as in DeVries et al. (2008). In this study, SSDs were employed for temperature and dissolved oxygen lethality and sublethal responses (DeVries et al. 2008). Specifically, this study focused on temperature and dissolved oxygen SSDs to provide information that can be used for re-evaluating current temperature standards for thermal discharges and dissolved oxygen standards in the state of Texas.

Background on Critical Thermal Maxima

Critical thermal maxima (CTM) is a commonly utilized temperature endpoint for fish, amphibian, and aquatic invertebrate species, so it was chosen to form the SSDs in this study. CTM is a laboratory approach to characterize temperature tolerance. In CTM studies, organisms are usually acclimated to a start temperature and exposed to a constant linear increase or decrease in temperature until a sublethal but near lethal endpoint is reached (Eaton 1996). The sublethal endpoint is defined as the pre-death thermal point at which movement becomes disorganized (Eaton 1996). Notably, CTM has been found to be dependent upon acclimation temperature (Jungreis 1968, Heinicke and Houston 1965, Lotshaw 1977).

The application of the CTM method has also shown a steady increase since the 1950s, becoming one of the most commonly utilized methods for temperature stressor testing today (Lutterschmidt 1997).

PROJECT OBJECTIVE AND TASK DESCRIPTIONS

The overall objective of this project was to evaluate published temperature and dissolved oxygen (DO) toxicity data for endemic Texas species in order to re-evaluate current temperature differentials and DO presumptions for TCEQ surface water quality criteria. Briefly, there were six tasks associated with this project outlined in the initial scope of work and Quality Assurance Project Plan (QAPP):

Task 1: Project Administration

The TTU Principal Investigator (PI) will provide administrative oversight of all in-house and consultant activities including preparing and submitting progress reports, tracking and reporting expenses for reimbursement, maintaining backup documentation, and provision of updates reflecting any changes relating to personnel.

These reports will detail all activities completed within the preceding time period, address any scheduling shortfalls, detail any significant problems, indicate equipment requirements, and include the status of deliverables for each task as well as narrative descriptions of the progress and findings of each task.

As part of Project Administration, the Principal investigator will schedule a quarterly meeting (December, March, June, and August) with the TCEQ in person or by conference call to report on the progress of the project and discuss the project tasks for the next quarter. Detailed meeting notes will be taken and included in the following quarterly progress report to the TCEQ. The PI will also participate in annual contractor evaluations. An annual self-evaluation as well as evaluations of subcontractors will be submitted at the end of each State of Texas fiscal year.

Task 2: Quality Assurance

The TTU PI will develop a QAPP which will be submitted to TCEQ. After review of the draft QAPP by TCEQ, comments and edits will be incorporated into the QAPP and a final QAPP will be submitted. The final QAPP will be submitted to TCEQ and then to the United States Environmental Protection Agency (EPA) Region 6 Quality Assurance Division for review and approval. Corrections or suggestions from the EPA will be reviewed and/or incorporated into the final QAPP. Analysis of data will not commence until the final QAPP has been approved by both EPA and TCEQ.

Amendments to the QAPP will be done as needed during the duration of this project due to changes in analysis, project organization, and other major items of the project. Amendments will be developed, signed, and submitted to the Project Manager. QAPP amendments will be distributed to all personnel on the distribution list for approval. Amendments must be approved and documented prior to implementation in the project. See below in the section Amendments to the QAPP for more detail.

Task 3: Review of historical temperature lethal and sublethal data in Texas for native fishes, aquatic invertebrates, and amphibians.

The PI and the TTU project team will conduct a review of published literature and data regarding temperature effects (both lethal and sublethal) to native fish, aquatic invertebrate, and amphibian species in Texas. The review will focus on applicable studies (lab and field), reports, and peer-reviewed journal

articles dealing primarily with temperature and its influence on water bodies within Texas or neighboring states (New Mexico, Oklahoma, Arkansas, and Louisiana). Of particular interest is the degree of temperature fluctuations above and below ambient temperature in different types of water bodies in different regions of the state. Seasonal effects on these temperature differentials are also of interest.

Data extracted from published studies will include at a minimum: (1) temperature toxicity value, (2) specific response variable measured, (3) response type (i.e., lethal or sublethal), (4) data source (publishing agency or citation of peer-reviewed literature), (5) type of study (field or lab), (6) spatial location of data for field studies, and (7) dominant land use at location of data collection (e.g. urban, suburban, agriculture, grassland, forested) for field studies.

Temperature toxicity data will be analyzed statistically. Details regarding potential statistical approaches are discussed in section B10 Data Management of this QAPP.

Task 4: Assessment of Other States Temperature Differential/Deltas

The PI and the TTU project team will review the temperature differentials used in all 50 State's temperature surface water quality standards for all water body types. Information that will be collected and organized into a database will include: (1) current differentials used by each state for different water body types, (2) implementation procedures/methods used by the state to apply the differentials in wastewater discharge permits, (3) mixing zone sizes applied to thermal discharges, and (4) identification of types of wastewater dischargers or situations/conditions in which exemptions from temperature maximum or differential requirements may be considered.

Task 5: Review of historical dissolved oxygen lethal and sublethal data in Texas for native fishes, aquatic invertebrates, and amphibians in marine and tidally-influenced water bodies.

The PI and the TTU project team will conduct a review of published literature and data regarding DO impacts (both lethal and sublethal) to native fish, aquatic invertebrate, and amphibian species found in marine and tidally-influenced water bodies in Texas. The review will focus on applicable studies (lab and field), reports, and articles dealing primarily with DO and its influence on species found in tidal water bodies within Texas or Louisiana.

Data extracted from published studies will include at a minimum: (1) DO toxicity values, (2) specific response variable reported, (3) response type (i.e., lethal or sublethal), (4) data source (publishing agency or citation of peer-reviewed literature), (5) type of study (field or lab), (6) spatial location of data for field studies, (7) dominant land use at location of data collection (e.g. urban, suburban, agriculture, grassland, forested) and (8) relevant water quality information associated with oxygen solubility (i.e., salinity or temperature) measured during field studies.

Task 6: Summarize and Report Information from Tasks 3, 4, and 5

The PI and the TTU project team will summarize and analyze the data regarding the effects of temperature and DO on native Texas species from the reviews conducted in Tasks 3, 4, and 5 into a written report. The data will also be provided in several electronic formats to facilitate future analyses and comparisons. In addition, a bibliographic Microsoft™ Excel database of peer reviewed literature and any agency reports used to prepare the databases will be provided. Scanned or original PDF versions of published reports and peer-reviewed papers will also be provided.

APPROACH AND METHODOLOGY

The objective of this project was to collect and evaluate published temperature and DO toxicity data for fish, amphibian, and aquatic invertebrate species endemic to Texas. This information will be used by TCEQ to re-evaluate current temperature differentials and DO presumptions for TCEQ criteria. The project does not generate original data but rather forms a collection of already published data that will be analyzed for patterns and trends relative to current TCEQ temperature and DO surface water quality standards. Only data and information published in peer-reviewed journal articles or state and federal agency publications were included in project databases for evaluation. We relied on the journal and agency review processes as the vetting mechanisms for quality assurance and quality control of the published data. Information and data collected for Task 4 of this project did not occur in published peer-reviewed journal articles, but rather in/on state agency reports and websites. Therefore, the requirement of data sourced from peer-reviewed publications did not apply to Task 4 of the current project, and we assumed information published in states registers, rulings, laws, and state supported websites were accurate. Surface water quality standards for temperature were selected from states with standards approved by the EPA, or whose standards are pending EPA approval.

General Data Acquisition

For this project, data were collected from previously published sources, reports, and/or websites and were non-direct measurements. For Tasks 3 and 5 (as described previously under Task Descriptions) the following data were extracted from published peer-reviewed studies: (1) temperature or DO toxicity values, (2) specific response variable reported, (3) response type (i.e., lethal or sublethal), (4) data source (publishing agency or citation of peer-reviewed literature), (5) type of study (field or lab), (6) spatial location of data for field studies, (7) dominant land use at location of data collection (e.g. urban, suburban, agriculture, grassland, forested) and (8) relevant water quality information associated with oxygen solubility (salinity or temperature) measured during field studies. For Task 4, the following information was collected from state and federal reports and/or websites and organized into a database: (1) current temperature differentials used by each state for different water body types, (2) implementation procedures/methods used by the state to apply the temperature differentials in wastewater discharge permits, (3) mixing zone sizes applied to thermal discharges, and (4) identification of types of wastewater dischargers or situations/conditions in which exemptions from temperature maximum or differential requirements may be considered.

In addition, the project scope is limited to temperature and DO effects on fish, amphibians, and aquatic invertebrates native to Texas. Therefore, one of the first sub-tasks was to develop taxon lists of these organisms to compare with data from the literature searches. We used Thomas et al. (2007) as the source for development of a native freshwater fish species list and Conant and Collins (1991) and Dixon (2000) as sources for development of a native amphibian species list (Tables 1 and 2). In order to confirm inclusion into the database regarding information/data on temperature and DO effects on aquatic invertebrates, reported species were compared to an online database of invertebrates found in Texas (http://www.austincc.edu/sziser/txaquaticinverts/) (Ziser 2008-2012) as well as the species lists in Appendix B of the document, "Surface Water Quality Monitoring Procedures, Volume 2: Methods for Collecting and Analyzing Biological Assemblage and Habitat Data". This is the taxonomic list used for Texas's Index of Biological Integrity (IBI) assessments.

Data Management

Data fields extracted from resources were populated in a common electronic format (i.e., Microsoft

Excel™ spreadsheets). Each of the tasks 3, 4, and 5 were comprised of separate and multiple databases. This will facilitate use of data because different tasks will likely be utilized differently (e.g., toxicity value database [Task 3] versus state temperature differential database [Task 4]) and they contain completely different types of data (e.g., temperature [Task 3] versus DO [Task 5]).

Specific Approach to Data Acquisition and Analyses

Temperature toxicity data (i.e., endpoint estimates such as LT50s) were analyzed using SSDs for species endemic to Texas. Species sensitivity relationships were modeled using JMP software (JMP SAS, 2013). SSDs are frequently used to identify risk of a stressor to a collection of species that vary in their sensitivity (Raimondo et al. 2008, Coffey et al. 2014). De Vries et al. (2008) suggested using SSDs to understand temperature effects to communities, particularly those that are localized in space or time such as that associated with thermal discharges.

Current TCEQ temperature criteria can be compared to the SSD to identify if temperature differential and maximum criteria are protective of sensitive taxa. Additionally, published works may only report physiological data at single temperatures or over a temperature range for a species (e.g., Warburg 1997) and not a gradient derived toxicity endpoint such as an LT50. In these cases, these data can be used to compare against the TCEQ criteria to identify risk to that species.

For SSDs, we follow standardized methodology described in the published literature and carefully considered issues such as the number of species used (Dowse et al. 2013) and the underlying distribution function (Newman et al. 2000, Wheeler et al. 2002, De Vries et al. 2008). If there were too few endemic Texas species with temperature toxicity data, these entries remained in the databases and can be used for individual comparisons to temperature standards. In calculations of the temperature SSD we also considered the temperature tolerance interval (TTI) described by De Vries et al. (2008). The relationship between the LT50, TTI, and acclimation temperature (T_a) can be used to make toxicity data that are derived from species using different T_a comparable. This approach can allow more data to be used within the same analysis and may have direct benefits for TCEQ goals regarding temperature differentials.

With use of SSDs, an LT50 or other endpoint is used as the toxicity benchmark. Single points such as the TCEQ maximum temperature criteria and other points associated with the criteria (i.e., the low or high end of the differential/delta) can be compared to the distribution of LT50s. It should be noted that temperature variation is not typically accounted for during toxicity exposure studies. For example, studies that simulate realistic daily low and high temperatures cyclically over a 24-hour exposure period are not frequently conducted. Although these types of datasets would be very useful for assessing temperature differentials, our research group has been working on these types of scenarios (Willming et al. 2013) and can confirm that the published literature is very limited. It should also be noted that the literature search may reveal data on temperature toxicity over time. These data would be described as the time it takes for a particular temperature to be lethal to 50% of a population. These endpoints are frequently reported in the literature as "LT50"; therefore, to avoid confusion during this project these types of data will be labeled as LTi50 if encountered.

Similar methods and approaches described for temperature were used when developing SSDs for DO with species endemic to Texas.

In the project scope of work and QAPP, it was proposed to examine and summarize the temperature and DO toxicity databases from a holistic perspective for assessing temperature and DO toxicity. It was anticipated that results and data from many studies would be valuable for understanding temperature and dissolved oxygen toxicity, but would be too unique to combine into a single analysis of multiple

datasets such as with SSDs. For this reason, all relevant data were collected and presented in the databases, whether they could be used for SSDs or not. In addition, it was proposed that if possible studies would be examined using meta-analytical techniques (MetaWin Version 2 methodology and software (Rosenberg et al. 2000)). A meta-analysis is an approach for examining the strength of broad, overarching patterns that occur across multiple studies and datasets (Gurevitch et al. 2000). A requisite for conducting a meta-analysis on temperature and DO toxicity data would be to obtain sufficient number of studies and/or datasets in which similar hypothesis tests were conducted using inferential statistics. It is the parameters used in those statistical tests that are used within a meta-analysis. We determined that there were insufficient hypothesis tests to be able to conduct a meta-analysis on these data. This was primarily an artifact of dose-response study designs or CTM designs in which effects are designed to occur.

Search Terms Used to Populate Databases

In order to populate databases, literature searches were conducted using Google Scholar and/or Web of Science (Thomson Scientific). For the temperature databases (Task 3) for both fish and amphibian species listed on our working vertebrate taxa lists, searches were conducted using the following search terms:

"temperature" AND [species name]
"critical thermal maxima" AND [species name]
"temperature toxicity" AND [species name]
"temperature-dependent toxicity" AND [species name]

For the temperature database for invertebrates, Appendix B of the document, "Surface Water Quality Monitoring Procedures, Volume 2: Methods for Collecting and Analyzing Biological Assemblage and Habitat Data" was used to guide with the family and orders. When a potential journal article was identified that was useable for the database, the species name was searched in the Aquatic Inverts of Texas Catalogue (Ziser, 2008-2012). This approach was utilized to limit the vast amount of literature on aquatic invertebrates. If the species was not listed in the catalogue (i.e., was not an invertebrate species endemic to Texas), it was not included in the database. For invertebrate taxa, searches were conducted using the following search terms:

"temperature" AND [order]
"temperature" AND [family]
"temperature toxicity" AND [order]
"temperature toxicity" AND [family]

For the dissolved oxygen databases (Task 5) for brackish and marine fish and invertebrates (no tidal or marine amphibians were identified), the species lists in Appendix B of the document, "Surface Water Quality Monitoring Procedures, Volume 2: Methods for Collecting and Analyzing Biological Assemblage and Habitat Data" were used. The following search statement was used for each marine and brackish water dwelling species on the list:

([species name] OR [common name]) AND ("dissolved oxygen" OR hypoxia OR hypoxic OR anoxia OR anoxic OR "low oxygen").

For each search, relevant data were extracted from the sources into a Microsoft Excel (Microsoft, Redmond, WA, USA) database and included the temperature toxicity value, the response variable measured, the response type (i.e. lethal, sublethal), the data source, the type of study (i.e., lab, field, etc.), the spatial location of data for field studies, and dominant land use at the location of data collection (i.e.,

suburban, rural, etc.). Similar endpoints were found for many species, but overall, endpoints across taxa were highly variable. Additionally, exposure scenarios, origin of the species, and acclimation temperature varied amongst studies. All data were checked for potential duplication because several of the databases reported studies that had already been located and identified from the literature. The reliability of an SSD will increase with a greater number of data points (DeVries et al. 2008); however, in the present study the availability of data was limiting, so selection criteria were not too strict. Data was not available for every Texas species compiled in these lists.

For the temperature standard across states database (Task 4), Google was searched for each of the 50 states using the search term:

[State] water quality standards for temperature

For most states this search yielded documents(s) that contained water quality standards and criteria. Forms ranged from broad state regulatory documents in which were embedded water quality standards rules to individual documents specifically focusing on water quality standards. Organization and presentation of water quality standards were quite variable among the states. These documents (PDFs) were then searched for relevant information. For temperature criteria, information on mixing zones, information on implementation procedures, and information on procedures or methods for exemptions, the following search terms were used to search the PDF:

"temperature"
"mixing zones"
"implementation"
"procedures"
"temperature procedures"
"exemptions"
"exceptions"
"variance"
"variances"
"permit variances"

In addition to these searches, the table of contents (if present) within the regulatory documents were searched for these or similar terms.

Generation of the SSDs

Some of the available data could be normalized for acclimation temperature, but many important data points were not. In order to consider all of the data available, SSDs for fish, amphibians, and invertebrates were generated without accounting for acclimation temperature, potentially introducing more variation into those SSDs. The data that could be normalized for acclimation temperature and that utilized a 20 °C acclimation temperature, were transformed into a temperature tolerance interval (TTI) for each species (i) using Equation 1 (DeVries et al., 2008; Urban, 1994). The TTI can be described as the interval by which a temperature can increase above the T_a (i.e., acclimation temperature) and cause the pre-death thermal endpoint for that species (CTM).

$$TTI_i = CTM - T_a \quad (1)$$

The SSD curve was fit with the log-probit distribution using the U.S. EPA's Species Sensitivity Distribution Generator (SSD_Generator_V1.xlt) (http://www.epa.gov/caddis/ da_software_ssd macro.html). The

methods are briefly described here. The first step was calculating the mean and log10 of the mean (Obs) for each taxon using data extracted from the literature. Data were then ranked from lowest to highest and converted ranks to proportions using Equation 2:

$$Proportion = \frac{(Rank-0.5)}{n}, n = \#\ of\ species \quad (2)$$

The proportions were transformed to probit, the inverse cumulative distribution function of the normal distribution. A mean of 5 was chosen to ensure all probit values were non-negative and a standard deviation of 1 was chosen. A slope and intercept for Log10 Mean (X axis) × Probit (Y axis) was generated and the log10 central tendency for the regression line was calculated using Equation 3a, and prediction intervals were calculated using Equation 3b:

$$Log10\ Central\ Tendency\ (Pred) = \frac{Probit-Intercept}{Slope} \quad (3a)$$

$$Pred\ Interval = \frac{(Obs-Pred)^2}{n-2} \quad (3b)$$

The Corrected Sum of Squares (CSSQ) was calculated by squaring the probit value and the sum of squares for each taxon. Probit values for all taxa were summed, squared, and divided by the number of taxa (Equation 4a), followed by subtraction of the average sum squared from the total sum of squares to generate the CSSQ (Equation 4b).

$$Avg\ Sum\ of\ Squares = \frac{\Sigma(Probit)^2}{n}, n = \#\ of\ taxa \quad (4a)$$

$$CSSQ = Total\ Sum\ of\ Squares - Avg\ Sum\ of\ Squares \quad (4b)$$

The Grand Mean and Point Error was calculated. The grand mean was calculated by taking the average of all log10 exposure values. Point Error was calculated (Equation 5).

$$Point\ Error = \left(\frac{MSE}{Slope^2}\right) * \left(1 + \frac{1}{n}\right) + \left(\frac{Pred-Grand\ Mean)^2}{CSSQ}\right) \quad (5)$$

Then to calculate the prediction intervals (PI), the critical t-value and Equation 6 were used to back convert from the log value.

$$logPI = logCentralTendency\ \pm tCrit\left(\sqrt{Point\ Error}\right) \quad (6)$$

Data Storage

Data were and continue to be stored electronically on a secure departmental server. The server is backed up every night. In addition, the PI has made additional backups of these databases and results (i.e., new versions of files as information is added or edited through time). This has been done approximately daily.

RESULTS AND INTERPRETATIONS

Temperature SSDs for Fish, Amphibians, and Invertebrates

For 68 Texas aquatic species, studies on the effect of temperature were selected based on quality criteria. For the SSDs, quality criteria for a study required that it be peer-reviewed literature that included a CTM for a Texas species. For each species in the SSD, the SSD was generated from the average values and standard deviations from multiple data for that species. Species sensitivities were then plotted using the EPA SSD Generator. From the SSDs for each endpoint, a hazardous temperature increase (HTI) was determined. Typically, HTIs are reported for a proportion of the species within a community. For example, HTI5 is the hazardous temperature increase for 5% of species entered into the SSD. From the available literature, five species sensitivity distributions were calculated for temperature. An aquatic vertebrate and aquatic invertebrate SSD were calculated using the TTI for data points that had an acclimation temperature of 20 °C. For instance, for authors that did not acknowledge an acclimation temperature of 20 °C, their data could not be analyzed via Equation 1. Three additional SSDs were generated using the available CTM data for Texas fish, amphibian, and invertebrate species.

TTI for Vertebrates

The first SSD considers sensitivities of the vertebrates using TTI as an endpoint (Table 3, Table 5, Figure 1). The most sensitive fish species was *Dorosoma petenense* with a TTI of 9.1 °C and the least sensitive fish was *Notropis stramineus* with a TTI of 16.1 °C. The most sensitive amphibian species was *Ambystoma maculatum* with a TTI of 17.2°C and the least sensitive species was *Gastrophyrne carolensis* tadpoles with a TTI of 21.0 °C. The fish dominate the left side of the SSD more so than the amphibians, indicating that fish are more sensitive to increasing temperatures than amphibians. With an HTI5 of 11.5 °C, the fish species *Dorosoma petenense* would not be within the protected temperature range.

TTI for Invertebrates

The second SSD considers the sensitivities of the invertebrates using CTM converted to TTI as an endpoint (Table 3, Table 5, Figure 2). The most sensitive invertebrate species was *Asellus aquaticus* with a TTI value of 12.5 °C and the least sensitive invertebrate species was *Libellula auripennis* with a TTI value of 23.0 °C. With an HTI5 value of 13.0 °C, *Asellus aquaticus* would be outside the range of protection.

CTM for Fish

The SSD for the CTM of Texas fish species ranged from 28.0 – 40.6 °C and includes 26 species of fish from six families (Acipenseridae, Amiidae, Clupeidae, Cyprinidae, Lepisosteidae, Polyodontidae) (Table 4, Table 5, Figure 3). *Scaphirhynchus platorynchus* was found to be the most sensitive to increases in temperature with a mean CTM of 28.0 °C and *Notropis buccula* was found to be the least sensitive to increases in temperature with a mean CTM of 40.6 °C. With a HTI5 value of 29.543 °C, *Scaphirhynchus platorynchus* would be outside the range of protection.

CTM for Amphibians

The SSD for the CTM of Texas amphibians ranged from 21.494 – 42.697 °C and includes 27 species of amphibians from 6 families (Ambystomatidae, Bufonidae, Hylidae, Microhylidae, Ranidae, and Salamandridae) (Table 4, Table 5, Figure 4). *Hyla chrysoscelis* was found to be the most sensitive to increases in temperature with a mean CTM of 21.494 °C and *Bufo marinus* was found to be the least

sensitive to increases in temperature with a mean CTM of 42.697 °C. With a HTI5 value of 26.393 °C, *Hyla chrysoscelis* would be outside the range of protection.

CTM for Invertebrates

The SSD for the CTM of Texas invertebrate species ranged from 30.945 – 42.740 °C, including 15 species (Table 4, Table 5, Figure 5). *Asellus aquaticus* was found to be the most sensitive to increases in temperature with a mean CTM of 30.945 °C, and *Libellula auripennis* was found to be the least sensitive to increases in temperature with a mean CTM of 42.740 °C. With an HTI5 value of 31.623 °C, *Asellus aquaticus* would be outside the range of protection.

Sublethal Temperature Thresholds

SSDs were also generated for sublethal thresholds, specifically optimal temperature for 18 fish species (Figure 6) and upper avoidance temperature for 11 fish and aquatic invertebrate species (Figure 7).

Dissolved Oxygen LC50s and Sublethal Responses for Marine and Estuarine Fish and Invertebrates and SSDs

Unlike with temperature, in which more standardized methods have been developed (e.g., use of CTM and TTI), dissolved oxygen effects on aquatic species were more variable among studies in terms of responses measured. This makes comparisons among studies, and by extension among species, difficult and mostly impractical for sublethal responses such as behavior, growth, and reproduction. The most prevalent response variable that was comparable among species were reported LC50s to dissolved oxygen. These values were used in species sensitivity distributions (Table 6-9, Figures 8-14).

For juvenile and adult fish species (Table 6, Figure 8), dissolved oxygen LC50s were lowest for *Leiostomus xanthurus* and greatest for *Harengula jaguana*, meaning the *H. jaguana* was the most sensitive species to dissolved oxygen stress of those tested, and *L. xanthurus* was the least sensitive. For larval fish species (Table 6, Figure 9), dissolved oxygen LC50s were lowest (i.e., least sensitive) for *Gobiosoma bosc* and greatest (i.e., most sensitive) for *Morone saxatilis*. For juvenile and adult invertebrates (Figure 10), dissolved oxygen LC50s were lowest (i.e., least sensitive) for *Paranais litoralis* and greatest (i.e., most sensitive) for *Palaemonetes pugio*. When considering fish and invertebrates together, juvenile and adult fish tend to be more sensitive to low dissolved oxygen than juvenile and adult aquatic invertebrates (Figure 11), and a similar pattern is observed when comparing larval fish and invertebrates (Figure 12).

Sublethal effects of low dissolved oxygen on fish and invertebrates should be considered, and numerous studies reporting sublethal responses to dissolved oxygen were detected. For generation of SSDs, two responses were abundant enough to conduct an analysis. These included the thresholds for loss of equilibrium and air-surface respiration (Tables 7 and 9, Figures 13 and 14). Dissolved oxygen effects on reduction of growth for fish species was also summarized (Table 8).

Survey of Temperature Standards and Criteria for Each of the U.S. States

States were highly variable in each approach for temperature standards and criteria. Some states had very simple not to exceed (NTE) thresholds and/or temperature differentials (e.g., maximum increase or change from ambient) that applied to all waters within the state (Tables 10-19). Alternatively, other states had intricate temperature standards either in the form of thresholds or differentials that applied to multiple site-specific waterways, multiple designated uses, seasonality/temporal categories (e.g., monthly), biological criteria, and combinations of all these factors (Tables 10-19). Several of these states

(e.g., Wisconsin and Pennsylvania) had NTE and differential values based on factor combinations that resulted in too many to be included within Tables 17 and 19, and the regulatory documents are referred to. All coastal states addressed freshwaters and saltwater habitats differently as did those states that had ecoregions that contained cold water and warm water habitats.

Several states approaches may be useful to the TCEQ regarding differentials. Other Gulf states such as Alabama, Louisiana, Florida, and Mississippi all use differentials in the water temperature standards (Tables 10, 11, 13, 14) and Montana has a framework of very specific temperature differential criteria (Table 15 and 20). It was observed that some states have specific definitions for ambient temperatures, and this varied among states (Table 20). Some states define ambient temperatures based on monthly averages (e.g., Minnesota), others define ambient based on season (e.g., Alabama), while Wyoming uses a maximum increase over the maximum daily ambient temperature to define their differential (Table 19). In some states, differentials are defined based on mixing zones (e.g., New Jersey where the differential is defined as maximum temperature increase outside the heat dissipation area) (Table 15).

States have addressed mixing zone procedures, exemptions/variances, and implementation procedures to widely varying degrees relative to temperature standards (Tables 21-23). The narrative within these tables should highlight a few cases for each of these aspects that could be useful tools or approaches for TCEQ. How the states address each of the aspects varied from very general paragraphs within the water quality regulatory document to specifics on processes or calculations. Oregon (Table 21) has a temperature specific document that contains specific information about temperature within mixing zones.

Databases Generated from this Project

1. Temperature toxicity to native Texas freshwater fish.
2. Temperature toxicity to native Texas amphibians.
3. Temperature toxicity to native Texas freshwater invertebrates.
4. Dissolved oxygen toxicity to native Texas marine and estuarine fish.
5. Dissolved oxygen to native Texas marine and estuarine invertebrates.
6. Temperature standards for water bodies in the fifty U.S. States and associated information on mixing zones, exemptions, variances, and implementation procedures specific for temperature standards.

All databases include collections of PDFs of the resources used to extract information. For the temperature and dissolved oxygen toxicity databases, this includes PDFs of the peer-reviewed journal articles that data was drawn from. For the temperature criteria database, this includes PDFs of state government documents containing the rules and regulations for water quality standards within the state, as well as any supplemental information.

Organization of Database and PDF Files Submitted

Databases as excel spreadsheets and PDFs of all resources were submitted via mail to TCEQ on a thumb drive in duplicate. This section describes the organization of those files. Files were first organized within project tasks and labeled Task3_Temperature Data, Task4_Review of State Temp Standards, and Task5_Dissolved Oxygen Data. Within each of the Task 3 and Task 5 folders were two folders labeled Databases and PDFs of sources, containing the Excel database files and the PDFs. The Task 4 folder contained two folders, one containing the databases and the other (State Folders) containing the PDF

documents of state water quality regulations and other information that were used for Task 4 within folders of each individual state.

SUMMARY

In summary, databases were generated for Task 3, Task 4, and Task 5 of the project. Patterns were assessed related to temperature toxicity to endemic Texas fish, amphibians, and invertebrate species and dissolved oxygen toxicity to endemic Texas marine and estuarine fish and invertebrate species. In addition, water quality standards specifically regarding temperature were evaluated for each of the fifty U.S. states. Temperature standards in the form of thresholds, differentials, and rates were assessed. As a whole, information generated from this project on biotic responses to temperature and dissolved oxygen in combination with the assessment of approaches used in other states will assist TCEQ in assessing current temperature and dissolved oxygen standards in the state of Texas.

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Table 1. Taxa list of endemic Texas freshwater fish species used for literature searches for temperature toxicity values.

Family	Genus	Species	Common Name
Petromyzontidae	*Ichthyomyzon*	*castaneus*	Chestnut Lamprey
	Ichthyomyzon	*gagei*	Southern Brook Lamprey
Acipenseridae	*Scaphirhynchus*	*platorynchus*	Shovelnose Sturgeon
Polyodontidae	*Polyodon*	*spathula*	Paddlefish
Lepisosteidae	*Atractosteus*	*spatula*	Alligator Gar
	Lepisosteus	*oculatus*	Spotted Gar
	Lepisosteus	*osseus*	Longnose Gar
	Lepisosteus	*platostomus*	Shortnose Gar
Amiidae	*Amia*	*calva*	Bowfin
Hiodontidae	*Hiodon*	*alosoides*	Goldeye
Anguillidae	*Anguilla*	*rostrata*	American Eel
Clupeidae	*Dorosoma*	*cepedianum*	Gizzard Shad
	Dorosoma	*petenense*	Threadfin Shad
Cyprinidae	*Campostoma*	*anomalum*	Central Stoneroller
	Campostoma	*ornatum*	Mexican Stoneroller
	Carassius	*auratus*	Goldfish
	Ctenopharygodon	*idella*	Grass Carp
	Cyprinella	*lepida*	Plateau Shiner
	Cyprinella	*lutrensis*	Red Shiner
	Cyprinella	*proserpina*	Proserpine Shiner
	Cyprinella	*venusta*	Blacktail Shiner
	Cyprinus	*carpio*	Common Carp
	Dionda	*argentosa*	Manantial Roundnose Minnow
	Dionda	*diaboli*	Devils River Minnow
	Dionda	*episcopa*	Roundnose Minnow
	Dionda	*nigrotaeniata*	Guadalupe Roundnose Minnow
	Dionda	*serena*	Nueces Roundnose Minnow
	Hybognathus	*amarus*	Rio Grande Silvery Minnow
	Hybognathus	*hayi*	Cypress Minnow
	Hybognathus	*nuchalis*	Mississippi Silvery Minnow
	Hybognathus	*placitus*	Plains Minnow
	Hybopsis	*amnis*	Pallid Shiner
	Luxilus	*chrysocephalus*	Striped Shiner
	Lythrurus	*fumeus*	Ribbon Shiner
	Lythrurus	*umbratilis*	Redfin Shiner
	Macrhybopsis	*aestivalis*	Speckled Chub
	Macrhybopsis	*hyostoma*	Shoal Chub
	Macrhybopsis	*marconis*	Burrhead Chub
	Macrhybopsis	*storeriana*	Silver Chub
	Macrhybopsis	*tetranema*	Peppered Chub
	Notemigonus	*crysoleucas*	Golden Shiner
	Notropis	*amabilis*	Texas Shiner

	Notropis	*atherinoides*	Emerald Shiner
	Notropis	*atrocaudalis*	Blackspot Shiner
	Notropis	*bairdi*	Red River Shiner
	Notropis	*braytoni*	Tamaulipas Shiner
	Notropis	*buccula*	Smalleye Shiner
	Notropis	*buchanani*	Ghost Shiner
	Notropis	*chalybaeus*	Ironcolor Shiner
	Notropis	*chihuahua*	Chihuahua Shiner
	Notropis	*girardi*	Arkansas River Shiner
	Notropis	*jemezanus*	Rio Gande Shiner
	Notropis	*maculatus*	Taillight Shiner
	Notropis	*oxyrhynchus*	Sharpnose Shiner
	Notropis	*potteri*	Chub Shiner
	Notropis	*sabinae*	Sabine Shiner
	Notropis	*shumardi*	Silverband Shiner
	Notropis	*stramineus*	Sand Shiner
	Notropis	*texanus*	Weed Shiner
	Notropis	*volucellus*	Mimic Shiner
	Opsopoedus	*emiliae*	Pugnose Shiner
	Phenacobius	*mirabilis*	Suckermouth Minnow
	Pimephales	*promelas*	Fathead Minnow
	Pimephales	*vigilax*	Bullhead Minnow
	Platygobio	*gracilis*	Flathead Chub
	Pteronotropis	*hubbsi*	Bluehead Shiner
	Rhinichthys	*cataractae*	Longnose Dace
	Semotilus	*atromaculatus*	Creek Chub
Catostomidae	*Carpiodes*	*carpio*	River Carpsucker
	Cycleptus	*elongatus*	Blue Sucker
	Erimyzon	*oblongus*	Creek Chubsucker

Table 2. Taxa list of endemic Texas amphibian species used for literature searches for temperature toxicity values.

Order	Family	Genus	Species	Common Name
Caudata	Sirenidae	*Siren*	*intermdedia*	Lesser Siren
	Sirenidae	*Siren*	*texana*	Rio Grande Lesser Siren
	Ambystomatidae	*Ambystoma*	*maculatum*	Spotted Salamander
	Ambystomatidae	*Ambystoma*	*opacum*	Marbled Salamander
	Ambystomatidae	*Ambystoma*	*talpoideum*	Mole Salamander
	Ambystomatidae	*Ambystoma*	*texanum*	Smallmouth Salamander
	Ambystomatidae	*Ambystoma*	*tigrinum*	Tiger Salamander
	Amphiumidae	*Amphiuma*	*tridactylum*	Three-toed Amphiuma
	Plethodontidae	*Desmognathus*	*auriculatus*	Southern Dusky Salamander
	Plethodontidae	*Eurycea*	*latitans*	Cascade Caverns Salamander
	Plethodontidae	*Eurycea*	*nana*	San Marcos Salamander
	Plethodontidae	*Eurycea*	*neotenes*	Texas Salamander
	Plethodontidae	*Eurycea*	*quadridigitata*	Dwarf Salamander
	Plethodontidae	*Eurycea*	*sosorum*	Barton Springs Salamander
	Plethodontidae	*Eurycea*	*tridentifera*	Comal Blind Salamander
	Plethodontidae	*Eurycea*	*troglodytes*	Valdina Farms Salamander
	Plethodontidae	*Plethodon*	*albagula*	Western Slimy Salamander
	Plethodontidae	*Plethodon*	*serratus*	Southern Red-backed Salamander
	Plethodontidae	*Typhlomolge*	*rathbuni*	Texas Blind Salamander
	Plethodontidae	*Typhlomolge*	*robusta*	Blanco Blind Salamander
	Proteidae	*Necturus*	*beyeri*	Gulf Coast Water Dog
	Salamandridae	*Notophthalmus*	*meridionalis*	Black Spotted Newt
	Salamandridae	*Notophthalmus*	*viridescens*	Eastern Newt
Anura	Rhinophrynidae	*Rhinophrynus*	*dorsalis*	Mexican Burrowing Toad
	Pelobatidae	*Scaphiopus*	*couchi*	Couch's Spadefoot
	Pelobatidae	*Scaphiopus*	*hurteri*	Hurter's Spadefoot
	Pelobatidae	*Spea*	*bombifrons*	Plains Spadefoot
	Pelobatidae	*Spea*	*multiplicata*	Mexican Spadefoot
	Leptodactylidae	*Eleutherodactylus*	*augusti*	Barking Frog
	Leptodactylidae	*Leptodactylus*	*labialis*	White-lipped Frog
	Leptodactylidae	*Syrrhophus*	*cystignathoides*	Rio Grande Chirping Frog
	Leptodactylidae	*Syrrhophus*	*guttilatus*	Spotted Chirping Frog
	Leptodactylidae	*Syrrhophus*	*marnocki*	Cliff Chirping Frog
	Hylidae	*Acris*	*crepitans*	Northern Cricket Frog
	Hylidae	*Hyla*	*arenicolor*	Canyon Tree Frog
	Hylidae	*Hyla*	*chrysoscelis*	Cope's Gray Tree Frog
	Hylidae	*Hyla*	*cinera*	Green Tree Frog
	Hylidae	*Hyla*	*squirella*	Squirrel Tree Frog
	Hylidae	*Hyla*	*versicolor*	Gray Tree Frog
	Hylidae	*Pseudacris*	*clarki*	Spotted Chorus Frog
	Hylidae	*Pseudacris*	*crucifer*	Spring Peeper
	Hylidae	*Pseudacris*	*streckeri*	Strecker's Chorus Frog

Hylidae	*Pseudacris*	*triseriata*	Striped Chorus Frog
Hylidae	*Smilisca*	*baudini*	Mexican Tree Frog
Bufonidae	*Bufo*	*americanus*	American Toad
Bufonidae	*Bufo*	*cognatus*	Great Plains Toad
Bufonidae	*Bufo*	*debilis*	Green Toad
Bufonidae	*Bufo*	*houstonensis*	Houston Toad
Bufonidae	*Bufo*	*marinus*	Giant Toad
Bufonidae	*Bufo*	*punctatus*	Red-spotted Toad
Bufonidae	*Bufo*	*speciosus*	Texas Toad
Bufonidae	*Bufo*	*valliceps*	Gulf Coast Toad
Bufonidae	*Bufo*	*velatus*	East Texas Toad
Bufonidae	*Bufo*	*woodhousii*	Woodhouse's Toad
Ranidae	*Rana*	*areolata*	Crawfish Frog
Ranidae	*Rana*	*berlandieri*	Rio Grande Leopard Frog
Ranidae	*Rana*	*blairi*	Plains Leopard Frog
Ranidae	*Rana*	*catesbeiana*	Bullfrog
Ranidae	*Rana*	*clamitans*	Green Frog
Ranidae	*Rana*	*grylio*	Pig Frog
Ranidae	*Rana*	*palustris*	Pickerel Frog
Ranidae	*Rana*	*pipiens*	Northern Leopard Frog
Ranidae	*Rana*	*sphenocephala*	Southern Leopard Frog
Microhylidae	*Gastrophryne*	*carolinensis*	Eastern Narrowmouth Toad
Microhylidae	*Gastrophryne*	*olivacea*	Great Plains Narrowmouth Toad
Microhylidae	*Hypopachus*	*variolosus*	Sheep Frog

Table 3. Mean TTI values (°C) calculated from Equation 1 for each fish, amphibian and invertebrate species utilized in Figure 1 and Figure 2 SSDs, including life history stages.

Species Name	Life History Stage	Mean TTI (°C)
Fish		
Dorosoma petenense	Adult	9.102
Cyprinella lutrensis	Adult	12.556
Pimephales promelas	Adult	13.069
Notropis atherinoides	Adult	14.700
Lythrurus umbratilis	Adult	15.500
Campostoma anomalum	Adult	15.500
Notemigonus crysoleucas	Adult	16.000
Notropis stramineus	Adult	16.100
Amphibians		
Ambystoma maculatum	Adult	17.200
Pseudacris triseriata	Adult	18.227
Pseudacris triseriata	Larva	18.391
Notophthalmus viridescens	Adult	19.113
Rana clamitans	Adult	19.400
Bufo americanus	Larva	20.188
Bufo woodhousii	Larva	20.314
Bufo americanus	Adult	20.330
Gastrophryne carolinesis	Adult	20.400
Bufo woodhousii	Adult	20.500
Gastrophryne carolinesis	Larva	20.950
Invertebrates		
Asellus aquaticus	Larva	12.516
Macromia illinoiensis	Larva	19.000
Celithemis spp	Larva	20.400
Odonata	Larva	20.459
Epitheca cynosure	Larva	21.200
Pachydiplax longipennis	Larva	22.009
Libellula auripennis	Larva	23.000

Table 4. Mean CTM values (°C) for each fish, amphibian, and aquatic invertebrate species utilized in species sensitivity distributions shown in Figures 3-5.

Species Name	Life History	Mean CTM (°C)
Fish		
Scaphirhynchus platorynchus	Adult	28.000
Dorosoma petenense	Adult	29.174
Rhinichthys cataractae	Adult	29.673
Lepisosteus osseus	Adult	31.500
Dorosoma cepedianum	Adult	32.208
Semotilus atromaculatus	Adult	32.566
Phenacobius mirabilis	Adult	32.744
Notemigonus crysoleucas	Adult	33.488
Pimephales promelas	Adult	33.912
Notropis atherinoides	Adult	33.934
Notropis stramineus	Adult	33.954
Notropis buchanani	Adult	34.000
Polyodon spathula	Adult	34.023
Carassius auratus	Adult	34.420
Cyprinella lutrensis	Adult	34.566
Campostoma anomalum	Adult	35.072
Lythrurus umbratilis	Adult	35.965
Amia calva	Adult	36.089
Luxilus chrysocephalus	Adult	36.200
Hybognathus placitus	Adult	36.962
Pimephales vigilax	Adult	37.296
Notropis girardi	Adult	38.600
Ctenopharygodon idella	Adult	38.746
Notropis oxyrhynchus	Adult	39.200
Cyprinus carpio	Adult	39.233
Notropis buccula	Adult	40.600
Amphibians		
Hyla chrysoscelis	Adult	21.494
Ambystoma texanum	Tadpole	25.543
Lithobates sphenocephalus	Tadpole	25.594
Rana palustris	Adult	30.321
Pseudacris triseriata	Tadpole	33.532
Rana catesbeiana	Adult	34.632
Ambystoma maculatum	Adult	35.827
Hyla squirella	Adult	36.500
Rana pipiens	Adult	36.524
Rana clamitans	Adult	36.578
Hyla cinera	Adult	36.600
Pseudacris triseriata	Adult	37.455
Notophthalmus viridescens	Adult	38.001
Rana catesbeiana	Tadpole	38.682

Hyla veriscolor	Adult	38.700
Bufo americanus	Tadpole	38.872
Bufo cognatus	Adult	39.162
Rana berlandieri	Adult	39.329
Rana pipiens	Tadpole	39.608
Acris crepitans	Adult	39.759
Bufo americanus	Adult	40.331
Bufo woodhousii	Adult	40.400
Bufo marinus	Adult	40.574
Bufo woodhousii	Tadpole	40.893
Gastrophryne carolinesis	Adult	40.897
Gastrophryne carolinesis	Tadpole	41.402
Bufo marinus	Tadpole	42.697
Invertebrates		
Asellus aquaticus	Larva	30.945
Isoperla namata	Larva	33.498
Protonemura capitata	Larva	33.680
Orconectes rusticus	Larva	33.699
Hydropsyche simulans	Larva	35.648
Procambarus clarkia	Larva	36.000
Caenis latipennis	Larva	37.800
Macromia illinoiensis	Larva	38.753
Macromia sp.	Larva	40.476
Celithemis sp.	Larva	40.637
Epitheca cynosure	Larva	40.750
Dragonflies (Odonata)	Larva	40.771
Pachydiplax longipennis	Larva	42.036
Libellua sp.	Larva	42.732
Libellula auripennis	Larva	42.740

Table 5. The slope, intercept, and R^2 for each species sensitivity distribution (Figures 1-5) generated by the U.S. EPA Species Sensitivity Distribution Generator (SSD_Generator_V1.xlt).

SSD	**Slope**	**Intercept**	R^2
Vertebrates TTI	9.794	-7.032	0.848
Invertebrates TTI	9.394	-7.115	0.717
Fish CTM	24.178	-32.198	0.971
Amphibian CTM	11.958	-13.642	0.746
Invertebrate CTM	21.149	-28.369	0.920

Table 6. Lethal concentrations of dissolved oxygen to fish species with life stage and test length information. A variety of LC values are reported as well as threshold lethal levels. The LC values are those used in Figures 6, 7, 9, and 10. LC and threshold values are mg/L of dissolved oxygen.

Common Name	Species	Life Stage	Test length (h)	LC05	LC10	LC50	LC90	LC95	Threshold /Lethal Conc.
Bay anchovy	*Anchoa mitchilli*	larvae	12			1.6			
Bay anchovy	*Anchoa mitchilli*	egg	12			2.8			
Bay anchovy	*Anchoa mitchilli*	larvae	24						1-2
Frillfin goby	*Bathygobius soporator*	juvenile/adult							0.26
Goldeye	*Hiodon alosoides*	juvenile/adult							1.2-1.5
Goldeye	*Hiodon alosoides*	juvenile/adult							0.7-1.6
Inland silverside	*Menidia beryllina*	larvae	24-96		1.7	1.4	1.3		
Inland silverside	*Menidia beryllina*	adult	24		2.07	1.94	1.8		
Naked goby	*Gobiosoma bosc*	larvae	24			1.3			
Naked goby	*Gobiosoma bosc*	larvae	24						1-2
Naked goby	*Gobiosoma bosc*	larvae	24						1.2-1.8
Naked goby	*Gobiosoma bosc*	juvenile	7						0.5-0.6
Naked goby	*Gobiosoma bosc*	adult	7						0.4
Pinfish	*Lagodon rhomboides*	juvenile	24		1.96	1.62	1.28		
Pinfish	*Lagodon rhomboides*								0.82*
Pinfish	*Lagodon rhomboides*								1.3
Red drum	*Sciaenops ocellatus*	juvenile	24		1.62	1.45	1.23		
Red drum	*Sciaenops ocellatus*	larvae	24		2.3	1.8	1.2		
Sailfin molly	*Poecilia latipinna*	juvenile	2						0.29
Scaled sardine	*Harengula jaguana*	juvenile	24		2.63, 2.72	2.12, 2.22	1.69, 1.7		
Sheepshead minnow	*Cyprinodon variegatus*	juvenile	2						0.22
Shovelnose sturgeon	*Scaphirynchus platorynchus*	larvae							2.5
Silver perch	*Bairdiella chrysoura*	juvenile/adult	24		2.4	1.1	0.5		
Spot	*Leiostomus xanthurus*		1	0.56		0.49		0.43	
Spot	*Leiostomus*		24	0.76		0.67		0.59	

	xanthurus								
Spot	*Leiostomus xanthurus*		96	0.81		0.7		0.6	
Spot	*Leiostomus xanthurus*	juvenile	12			1.1			
Spot	*Leiostomus xanthurus*								0.82*
Spotted seatrout	*Cynoscion nebulosus*	juvenile	48		2.26	1.88	1.58		
Spotted seatrout	*Cynoscion nebulosus*	juvenile	24		2.26	1.89	1.58		
Striped bass	*Morone saxatilis*	juvenile	96		1.9	1.6	1.2		
Striped bass	*Morone saxatilis*	postlarvae	24-96		3	2.4	1.9		
Striped mullet	*Mugil cephalus*	juvenile	48		1.7	1.38	1.1		
Striped mullet	*Mugil cephalus*	juvenile	24		1.7	1.39	1.1		
Striped mullet	*Mugil cephalus*	egg	24, 48						4.5-5
Striped mullet	*Mugil cephalus*	larvae	24, 48, 72						4.8-5.4
Striped mullet	*Mugil cephalus*	larvae	96						6.4-7.9

Table 7. Dissolved oxygen threshold to fish species for loss of equilibrium. Threshold values are mg/L of dissolved oxygen.

Species	Life Stage	Conditions	DO (mg/L)
Cyprinodon variegatus	juvenile	threshold for loss of equilibrium (*fish were held in sealed containers at 7.5 mg/l, then oxygen was reduced by one half every 20 min)	0.22
Poecilia formosa	juvenile	threshold for loss of equilibrium (fish were held in sealed containers at 7.5 mg/l, then oxygen was reduced by one half every 20 min)	0.3
Poecilia latipinna	juvenile	threshold for loss of equilibrium (fish were held in sealed containers at 7.5 mg/l, then oxygen was reduced by one half every 20 min)	0.29
Gambusia affinis	juvenile	threshold for loss of equilibrium (fish were held in sealed containers at 7.5 mg/l, then oxygen was reduced by one half every 20 min)	1.39
Fundulus zebrinus	NS	threshold for loss of equilibrium (oxygen reduced at rate of 0.62 mg/l/min)	1.25
Cyprinodon rubrofluviatilis	NS	threshold for loss of equilibrium (oxygen reduced at rate of 0.62 mg/l/min)	0.95
Bathygobius soporator	juvenile or adult (NS)	threshold for loss of equilibrium (oxygen was reduced by 1/2 every 12 min)	0.26

Table 8. Dissolved oxygen effects on reduction in growth for fish species. Common response among these data is percent reduction in growth.

Species	Life Stage	Response Conditions	% Reduction	DO (mg/L)
Fundulus grandis	adult	no significant effect on specific growth rate	0	(cyclic) 1.4-5.5
Fundulus grandis	adult (female)	53% reduction in specific growth	53	1.34
Fundulus grandis	adult (male)	67% reduction in specific growth	67	1.34
Gobiosoma bosc	embryo	no significant effect on length at hatching	0	1.74
Morone saxatilis	juvenile	no significant reduction in growth rate	0	5.8
Poecilia reticulata	juvenile	no significant effect on specific growth rate	0	0.5
Esox lucius	juvenile	5% reduction in % weight gain	5	5.39
Morone saxatilis	juvenile	significant (7%) reduction in growth rate	7	4.8
Morone saxatilis	juvenile	significant (9%) reduction in growth rate	9	5.3
Paralichthys lethostigma	juvenile	11% reduction in growth rate	11	4.74
Esox lucius	juvenile	14% reduction in % weight gain	14	2.91
Esox lucius	juvenile	17% reduction in food conversion efficiency	17	2.6
Morone saxatilis	juvenile	17% reduction in growth (weight)	17	3.5
Paralichthys lethostigma	juvenile	23% reduction in growth rate	23	(cyclic) 2.8-6.1
Leiostomus xanthurus	juvenile	38% reduction in growth rate	38	1.5
Paralichthys lethostigma	juvenile	46% reduction in growth rate	46	2.79
Paralichthys lethostigma	juvenile	50% reduction in growth rate	50	4
Esox lucius	juvenile	66% reduction in % weight gain	66	2.6
Leiostomus xanthurus	juvenile	89%% reduction in growth rate	89	1.5
Oncorhynchus mykiss	juvenile or adult (NS)	no significant effect on growth (weight)	0	5.8
Esox lucius	larvae	7% reduction in growth (length) (flow rate of 60 ml/min)	7	4.9
Esox lucius	larvae	12% reduction in growth (length) (flow rate of 30 ml/min)	12	3.4
Esox lucius	larvae	14% reduction in growth (length) (flow rate of 30 ml/min)	14	3.2
Menidia beryllina	larvae	16% decrease in length of 9-d post hatch larvae	16	2.7

Esox lucius	larvae	26% reduction in growth (length) (flow rate of 60 ml/min)	26	2.9
Esox lucius	larvae	27% reduction in growth (length) (flow rate of 60 ml/min)	27	2.6
Cyprinodon variegatus	larvae	44% decrease in length of post hatch larvae	44	2.4

Table 9. Dissolved oxygen threshold to fish species for air-surface respiration. Threshold values are mg/L of dissolved oxygen.

Species	Life Stage	Conditions	DO (mg/L)
Fundulus grandis	juvenile or adult	threshold for ASR	0.5
Poecilia reticulata	juvenile	threshold for ASR	2.7
Lagodon rhomboides	juvenile or adult (NS)	threshold for ASR	1
Megalops atlanticus	juvenile	threshold for ASR	1.98
Lucania parva	juvenile	threshold for ASR (*DO was lowered over the course of a few hours from ~7 to <1 mg/l)	0.91
Menidia beryllina	juvenile	threshold for ASR (DO was lowered over the course of a few hours from 7 to <1 mg/l)	1.04
Cyprinodon variegatus	juvenile	threshold for ASR (DO was lowered over the course of a few hours from 7 to <1 mg/l)	1
Gambusia affinis	NS	threshold for ASR	3.2
Poecilia latipinna	adult	threshold for 10% time spent in ASR	1
Gambusia affinis	NS	threshold for ASR	3.5
Poecilia latipinna	adult	threshold for 10% time spent in ASR	1

Table 10. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for Alabama, Alaska, Arizona, Arkansas, and California. NTE = Not to exceed.

Description of Standard	Type of Standard	AL	AK	AZ	AR	CA
NTE Stream, lakes, reservoirs	T	90.0				
Stream, lakes, reservoirs (Cahaba and Tallapoosa basins): NTE	T	86.0				
In stream rise (°F) above ambient (Stream, Lakes, Reservoirs)	D	5.0				
In stream rise (°F) above ambient (Coastal, Estuaries) - Oct-May	D	4.0				
In stream rise (°F) above ambient (Coastal, Estuaries) - Jun-Sep	D	1.5				
NTE agriculture, stock, irrigation	T		86.0			
NTE aquaculture	T		68.0			
NTE drinking water	T		59.0			
NTE aquaculture (migration routes, rearing areas)	T		59.0			
NTE aquaculture (spawning areas, egg/fry incubation)	T		55.4			
NTE industrial	T		77.0			
Max allowable increase Aquatic Wildlife Warm	D			3.0		
Max allowable increase Aquatic Wildlife Effluent Dominated	D			3.0		
Max allowable increase Aquatic Wildlife Cold	D			1.0		
Max allowable increase to any water body	D				5.0	
Rise above ambient Cold Interstate waters	D					0.0
Rise above ambient Warm Interstate waters	D					5.0
Rise above ambient Costal Waters	D					4.0
Rise above ambient Enclosed Bays	D					4.0
Rise above ambient Estuaries	D					4.0

Table 11. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for Colorado, Connecticut, Delaware, Florida, and Georgia. NTE = Not to exceed.

Description of Standard	Type of Standard	CO	CT	DE	FL	GA
Rise above ambient Cold Interstate waters	D	5.4				
NTE Cold Water	T	68.0				
Rise above ambient Warm Interstate waters	D	5.4				
NTE Warm Water	T	68.0				
NTE drinking water, fish and wildlife, recreation, industry, agricultural uses (class AA)	T		85.0			
Rise above ambient - drinking water, fish and wildlife, recreation, industry, agricultural uses (class AA)	D		4.0			
NTE fish and wildlife, potential drinking water, recreation, navigation, industry, agricultural uses (class A)	T		85.0			
Rise Above Ambient - fish and wildlife, potential drinking water, recreation, navigation, industry, agricultural uses (class A)	D		4.0			
NTE fish and wildlife, recreation, navigation, industry, agricultural uses (class B)	T		85.0			
Rise Above Ambient - fish and wildlife, recreation, navigation, industry, agricultural uses (class B)	D		4.0			
NTE marine fish and wildlife, shellfish, recreation, navigation, industry (class SA)	T		83.0			
Rise Above Ambient - marine fish and wildlife, shellfish, recreation, navigation, industry (class SA)	D		4.0			
Rise Above Ambient - marine fish and wildlife, shellfish, recreation, navigation, industry during July-Sept (class SA)	D		1.5			
NTE marine fish and wildlife, commercial shellfish harvesting, recreation, navigation, industry (class SB)	T		83.0			
Rise Above Ambient - marine fish and wildlife, commercial shellfish harvesting, recreation, navigation, industry (class SB)	D		4.0			
Rise Above Ambient - marine fish and wildlife, commercial shellfish harvesting, recreation, navigation, industry during July-Sept (class SB)	D		1.5			
Fresh water: Max Rise above ambient	D			5.0		
Fresh water: No human-induced increase of the true daily mean temp above:	T			82.0		
Fresh water: No human-induced increase of the daily maximum temp above:	T			86.0		
Marine Waters: Max Rise above ambient	D			4.0		
Marine Waters: No human-induced increase of the true daily mean temp above:	T			84.0		

Marine Waters: No human-induced increase of the daily maximum temp above:	T			87.0		
Cold Water Fisheries: Max Rise above ambient	D			5.0		
Cold Water Fisheries: No human-induced increase of the true daily mean temp above:	T			75.0		
North Zone: Max Temp - Streams	T				90.0	
North Zone: Max rise over ambient - Streams	D				5.0	
Peninsula: Max Temp - Streams	T				92.0	
Peninsula: Max rise over ambient - Streams	D				5.0	
North Zone: Max Temp - Lakes	T				90.0	
North Zone: Max rise over ambient - Lakes	D				3.0	
Peninsula: Max Temp - Lakes	T				92.0	
Peninsula: Max rise over ambient - Lakes	D				3.0	
North Zone: Max Temp - Coastal Summer	T				92.0	
North Zone: Max rise over ambient - Coastal Summer	D				2.0	
Peninsula: Max Temp - Coastal Summer	T				92.0	
Peninsula: Max rise over ambient - Coastal Summer	D				2.0	
North Zone: Max Temp - Coastal Non-summer	T				90.0	
North Zone: Max rise over ambient - Coastal Non-summer	D				4.0	
Peninsula: Max Temp - Coastal Non-summer	T				90.0	
Peninsula: Max rise over ambient - Coastal Non-summer	D				4.0	
North Zone: Max Temp - Open Water	T				97.0	
North Zone: Max rise over ambient - Open Water	D				17.0	
Peninsula: Max Temp - Open Water	T				97.0	
Peninsula: Max rise over ambient - Open Water	D				17.0	
NTE Temperature: Drinking, Recreation, fishing waters	T					90.0
Max rise over ambient: Freshwater - Drinking, Recreation, fishing waters	D					5.0
Max rise over ambient: Estuarine - Recreation, fishing waters	D					1.5
Max rise over ambient: Secondary Trout Waters - Drinking, Recreation, fishing waters	D					2.0
Max rise over ambient: Wild Rivers	D					0.0
Max rise over ambient: Scenic Rivers	D					0.0

Table 12. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for Hawaii, Idaho, Illinois, Indiana, and Iowa. NTE = Not to exceed.

Description of Standard	Type of Standard	HI	ID	IL	IN	IA
Inland water criteria for streams: Shall not vary from ambient by	D	1.8				
Inland water criteria for elevated wetlands: Shall not vary from ambient by	D	1.8				
Inland water criteria for estuaries: Shall not vary from ambient by	D	1.8				
Embayment: Shall not vary from ambient by	D	1.8				
Open coastal waters: Shall not vary from ambient by	D	1.8				
Oceanic waters: Shall not vary from ambient by	D	1.8				
Kona (west) Coast: Shall not vary from ambient by	D	1.8				
Mixing zones: NTE temperature	T	86.0				
Mixing zones: Max rise over ambient	D	5.4				
Cold Water: NTE	T		71.6			
Cold Water: NTE for max daily average	T		66.2			
Cold Water Lakes: Max change over ambient	D		0.0			
Salmonid spawning sites: NTE temperature	T		55.4			
Salmonid spawning sites: Max. daily average NTE	T		48.2			
Bull Trout: Weekly Max temp NTE during (June, July, Aug)	T		55.4			
Bull Trout: Weekly Max temp NTE during (Sept, Oct)	T		48.2			
Seasonal Cold Water: Daily Max. NTE	T		78.8			
Seasonal Cold Water: Daily Avg. NTE	T		73.4			
Warm Water: NTE	T		91.4			
Warm Water: Max daily avg. NTE	T		84.2			
Warm Water Lakes: Max change over ambient	D		0.0			
General WQ Standards: Max change from ambient	D			5.0		
General WQ Standards in Main Rivers: Max change above ambient	D			3.0		
General WQ Standards in Main Rivers: NTE more than 1% of h during a 12 month period for Dec-Mar.	T			60.0		
General WQ Standards in Main Rivers: NTE more than 1% of h during a 12 month period for Apr-Nov.	T			90.0		
Public and food processing water supply: NTE more than 5% of time.	T			93.0		
Public and food processing water supply: NTE at any time.	T			100.0		
Lake Michigan Basin Existing Sources: Max rise above ambient	D			3.0		
Lake Michigan Basin Existing Sources: NTE (Jan-Mar)	T			45.0		
Lake Michigan Basin Existing Sources: NTE (Apr)	T			55.0		
Lake Michigan Basin Existing Sources: NTE (May)	T			60.0		

Lake Michigan Basin Existing Sources: NTE (Jun)	T			70.0		
Lake Michigan Basin Existing Sources: NTE (Jul-Sept)	T			80.0		
Lake Michigan Basin Existing Sources: NTE (Oct)	T			65.0		
Lake Michigan Basin Existing Sources: NTE (Nov)	T			60.0		
Lake Michigan Basin Existing Sources: NTE (Dec)	T			50.0		
Lake Michigan Basin Sources under construction: discharge NTE ambient temps by	T			20.0		
Streams: Max temp rise above ambient	D				5.0	
Lakes and Reservoirs: Max temp rise above ambient	D				3.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Jan	T				50.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Feb	T				50.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Mar	T				60.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Apr	T				70.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with May	T				80.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with June	T				87.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with July	T				89.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Aug	T				89.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Sept	T				87.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Oct	T				78.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Nov	T				70.0	
Ohio River Main Stem: NTE 3F above value for more than 1% of h in the 12 month period ending with Dec	T				57.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Jan	T				50.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Feb	T				50.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Mar	T				60.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Apr	T				70.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with May	T				80.0	

Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with June	T				90.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with July	T				90.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Aug	T				90.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Sept	T				90.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Oct	T				78.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Nov	T				70.0	
Indiana Streams: NTE 3F above value for more than 1% of h in the 12 month period ending with Dec	T				57.0	
Interior streams or Big Sioux River: Max increase over ambient	D					5.4
Interior streams or Big Sioux River: Rate of temp change NTE / h	R					1.8
Interior streams or Big Sioux River: NTE temperature	T					89.6
Cold water fisheries: Max increase over ambient	D					3.6
Cold water fisheries: Rate of temp change NTE / h	R					1.8
Cold water fisheries: NTE temperature	T					68.0
Lakes and Reservoirs: Max increase over ambient	D					3.6
Lakes and Reservoirs: Rate of temp change NTE / h	R					1.8
Lakes and Reservoirs: NTE temperature	T					89.6
Missouri River: Max increase over ambient	D					5.4
Missouri River: Rate of temp change NTE / h	R					1.8
Missouri River: NTE temperature	T					89.6
Mississippi River: Max increase over ambient	D					5.4
Mississippi River: Rate of temp change NTE / h	R					1.8
Mississippi River, Zone II, Jan-Dec: NTE temperature ranges from 4C-29C (see 61.3(3))	T					84.2
Mississippi River, Zone III, Jan-Dec: NTE temperature ranges from 7C-30C (see 61.3(3))	T					86.0

Table 13. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for Kansas, Kentucky, Louisiana, Maine, and Maryland. NTE = Not to exceed.

Description of Standard	Type of Standard	KS	KY	LA	ME	MD
Max increase over ambient beyond the mixing zone	D	5.4				
Max decrease over ambient beyond the mixing zone	D	5.4				
Aquatic life use: Special - NTE beyond mixing zone	T	89.6				
Aquatic life use: Expected - NTE beyond mixing zone	T	89.6				
Aquatic life use: Restricted - NTE beyond mixing zone	T	89.6				
Aquatic life: NTE	T		89.0			
Lakes and reservoirs that support trout: Max increase over ambient	D		0.0			
Fresh Water, Streams and Rivers: Max. rise above ambient	D			5.0		
Fresh Water, Streams and Rivers: Max. rise above ambient	D			3.0		
Fresh Water: NTE	T			90.0		
Estuarine and coastal: Max. rise above ambient, Oct-May	D			4.0		
Estuarine and coastal: Max. rise above ambient, June-Sept	D			2.0		
Estuarine and coastal: NTE due to human influence	T			95.0		
Lakes or Ponds: Max. rise above ambient	D				5.0	
Freshwaters: NTE outside a mixing zone	T				85.0	
Tidal water: Max. rise above the monthly mean of the daily maximum ambient temperature (outside mixing zone)	D				4.0	
Tidal water: Max. rise above the monthly mean of the daily maximum ambient temperature (outside mixing zone), June-Sept	D				1.5	
Tidal water: NTE outside a mixing zone	T				85.0	
Class I-contact recreation and nontidal warm water aquatic life: NTE outside a mixing zone or the ambient temp, whichever is greater	T					90.0
Class I-P-contact recreation, nontidal warm water aquatic life, public water supply: NTE outside a mixing zone or the ambient temp, whichever is greater	T					90.0
Class II-P- Support of estuarine and marine life and shellfish harvesting, public water supply: NTE outside a mixing zone or the ambient temp, whichever is greater	T					90.0
Class III- Nontidal cold water: NTE outside a mixing zone	T					68.0
Class III-P- Nontidal cold water, public supply: NTE outside a mixing zone	T					68.0
Class IV- Recreational Trout waters: NTE outside a mixing zone or the ambient temp, whichever is greater	T					75.0
Class IV-P- Recreational Trout waters, public supply: NTE outside a mixing zone or the ambient temp, whichever is greater	T					75.0

Table 14. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for Massachusetts, Michigan, Minnesota, Mississippi, and Missouri. NTE = Not to exceed.

Description of Standard	Type of Standard	MA	MI	MN	MS	MO
Class A - cold water: NTE	T	68.0				
Class A - cold water: Max increase above ambient	D	1.5				
Class A - warm water: NTE	T	83.0				
Class A - warm water: Max increase above ambient	D	1.5				
Class B - cold water fishery: NTE	T	68.0				
Class B - cold water fishery: Max increase above ambient	D	3.0				
Class B - warm water fishery: NTE	T	83.0				
Class B - warm water fishery: Max increase above ambient	D	3.0				
Class C, SC: NTE	T	85.0				
Class C, SC: Max increase above ambient	D	5.0				
Class SA: NTE or a max daily mean of 80F	T	85.0				
Class SA: Max increase above ambient	D	1.5				
Class SB: NTE or a max daily mean of 80F	T	85.0				
Class SB: Max increase above ambient (July-Sept)	D	1.5				
Class SB: Max increase above ambient (Oct-June)	D	4.0				
Great lakes and connecting waters, inland lakes: Max increase above ambient after mixing	D		3.0			
Cold water rivers, streams, impoundments: Max increase above ambient	D		2.0			
Warm water rivers, streams, impoundments: Max increase above ambient	D		5.0			
Class 2A - aquatic life and recreation: Max increase above ambient	D			0.0		
Class 2Bd, Streams: Max increase above ambient based on monthly avg. of max daily temps	D			5.0		
Class 2Bd, Lakes: Max increase above ambient based on monthly avg. of max daily temps	D			3.0		
Class 2Bd, Streams and Lakes: NTE	T			86.0		
Class 2B, Streams: Max increase above ambient based on monthly avg. of max daily temps	D			5.0		
Class 2B, Lakes: Max increase above ambient based on monthly avg. of max daily temps	D			3.0		
Class 2B, Streams and Lakes: NTE	T			86.0		
Class C, Streams: Max increase above ambient based on monthly avg. of max daily temps	D			5.0		
Class C, Lakes: Max increase above ambient based on monthly avg. of max daily temps	D			3.0		

Class C, Streams and Lakes: NTE	T			86.0		
Class 2D - wetlands: Max increase above ambient	D			0.0		
Streams, lakes, reservoirs: NTE	T				90.0	
Streams, lakes, reservoirs: Max increase above ambient	D				5.0	
Tennessee River: NTE	T				86.0	
Tennessee River when ambient >90F: Max increase above ambient	D				0.0	
Coastal, estuarine waters: NTE	T				90.0	
Coastal, estuarine waters: Max increase above ambient (Oct-May)	D				4.0	
Coastal, estuarine waters: Max increase above ambient (June-Sept)	D				1.5	
Warm water: NTE	T					90.0
Cool water: NTE	T					84.0
Cold water: NTE	T					68.0
Warm water: Max. change	D					5.0
Cool water: Max. change	D					5.0
Cold water: Max. change	D					2.0
Mississippi River: Outside mixing zone cannot exceed listed limits (see table in document) by more than	D					3.0

Table 15. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for Montana, Nebraska, Nevada, New Hampshire, and New Jersey. NTE = Not to exceed.

Description of Standard	Type of Standard	MT	NE	NV	NH	NJ
A-Closed Class: Max increase above ambient	D	0.0				
A-1 Class: Max increase allowed within range of 32-66F (See standards for other ranges)	D	1.0				
B-1 Class: Max increase allowed within range of 32-66F (See standards for other ranges)	D	1.0				
B-2 Class: Max increase allowed within range of 32-66F (See standards for other ranges)	D	1.0				
B-3 Class: Max increase allowed within range of 32-77F (See standards for other ranges)	D	3.0				
C-1 Class: Max increase allowed within range of 32-66F (See standards for other ranges)	D	1.0				
C-2 Class: Max increase allowed within range of 32-66F (See standards for other ranges)	D	1.0				
I Class: Max increase above ambient	D	0.0				
C-3 Class: Max increase allowed within range of 32-77F (See standards for other ranges)	D	3.0				
Aquatic Life: Max increase above ambient	D		5.0			
Aquatic Life - Missouri River (specific region): NTE	T		85.0			
Aquatic Life - Missouri River (specific region): Max change from ambient	D		4.0			
Aquatic Life - Cold Water: NTE	T		72.0			
Aquatic Life - Cold Water: Max change from ambient	D		5.0			
Aquatic Life - Warm Water: NTE	T		90.0			
Aquatic Life - Impoundments: Max increase from ambient at surface	D		3.0			
Class A waters: Max change from ambient	D				0.0	
FW2-TP class: Max increase over ambient outside heat dissipation area	D					1.08
FW2-TM class: Max increase over ambient outside heat dissipation area	D					2.06
FW2-NT class: Max increase over ambient outside heat dissipation area	D					5.04
SE & SC class: Max increase over ambient outside heat dissipation area (Sept-May)	D					3.96
SE & SC class: Max increase over ambient outside heat dissipation area (June-Aug)	D					1.44
FW2-TP class: Daily max NTE	T					71.6

FW2-TM class: Daily max NTE	T					77.0
FW2-NT class: Daily max NTE	T					87.8
SE class: NTE	T					84.9
SC class: NTE	T					80.1

Table 16. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for New Mexico, New York, North Carolina, North Dakota, and Ohio. NTE = Not to exceed.

Description of Standard	Type of Standard	NM	NY	NC	ND	OH
Stream: Max increase over ambient (as measured above the point of introduction, and is 0F if site specific max is attained)	D	5.0				
Lake: Max increase over ambient (as measured above the point of introduction, and is 0 F if site specific max is attained)	D	3.0				
Nontrout Waters: Surface NTE	T		90.0			
Nontrout Waters: Max change from ambient (specific area and volume calculations apply and NTE 86F)	D		5.0			
Trout Waters: Max change from ambient (June-Sept)	D		2.0			
Trout Waters: Max increase from ambient (Oct-May) and NTE 50F	D		5.0			
Lakes: Max increase from ambient	D		3.0			
Coastal Waters: Max change from ambient (Oct-June)	D		4.0			
Coastal Waters: Max change from ambient (July-Sept)	D		1.5			
Estuaries: Surface NTE	T		90.0			
Estuaries: Max increase from ambient (specific area, volume, and spatial conditions apply and NTE 83F)	D		4.0			
Estuaries: Max increase from ambient (July-Sept) and ambient is >83F	D		1.5			
Enclosed Bays: Max increase from ambient	D		0.0			
Class C Waters (mountain, upper Piedmont): Max increase over ambient	D			5.0		
Class C Waters (mountain, upper Piedmont): NTE	T			84.2		
Class C Waters (lower Piedmont, coastal plain): Max increase over ambient	D			5.0		
Class C Waters (lower Piedmont, coastal plain): NTE	T			89.6		
Class C Waters (trout waters): Max increase over ambient	D			0.9		
Class C Waters (trout waters): NTE	T			68.0		
Class SC Waters (tidal salt waters): Max increase over ambient (June-Aug)	D			1.4		
Class SC Waters (tidal salt waters): Max increase over ambient (Sept-May)	D			4.0		
Class SC Waters (tidal salt waters): NTE	T			89.6		
Class I Streams: NTE	T				85.0	
Class I Streams: Max increase over ambient	D				5.0	
Class IA Streams: NTE	T				85.0	
Class IA Streams: Max increase over ambient	D				5.0	

Class II Streams: NTE	T				85.0	
Class II Streams: Max increase over ambient	D				5.0	
Class III Streams: NTE	T				85.0	
Class III Streams: Max increase over ambient	D				5.0	
Lakes and Reservoirs: NTE in the hypolimnion	T				59.0	
Lakes and Reservoirs: NTE (Except Nelson Lake)	T				85.0	
Lakes and Reservoirs: Max increase over ambient (Except Nelson Lake)	D				5.0	
Lakes and Reservoirs: NTE in Lake Sakakawea (volume restrictions apply)	T				59.0	
Exceptional warm water habitat: Max increase over ambient	D					0.0
Cold water habitat: Max increase over ambient	D					0.0

Table 17. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for Oklahoma, Oregon, Pennsylvania, Rhode Island, and South Carolina. NTE = Not to exceed. * = the reader is referred to the regulatory document because NTE and differential values exist for a multiple factor combinations (e.g., specific waterways, seasonality/temporal categories, and/or biological criteria) and are too numerous to list.

Description of Standard	Type of Standard	OK	OR	PA	RI	SC
WWAC Lakes: Max increase from ambient outside mixing zone	D	5.0				
WWAC Lakes, Lakes: Max increase from ambient in water column	D	3.1				
WWAC Lakes, Cool water streams: NTE	T	84.0				
WWAC Lakes, Trout Fishery Streams: NTE	T	68.0				
WWAC Lakes, Warm water streams and lakes: Max increase over critical temperature	D	5.0				
WWAC Lakes, Arkansas River from Red Rock Creek to headwaters of Keyston Res.: NTE	T	93.9				
Salmon+Steelhead present: 7 d avg. max. temp. NTE	T		55.4			
Core cold water habitat: 7 d avg. max. temp. NTE	T		60.8			
Salmon+Trout rearing and migration: 7 d avg. max. temp. NTE	T		64.4			
Natural Lakes: Max increase over ambient	D		0.5			
Oceans and Bays: Max increase over ambient	D		0.5			
Multiple NTE standards used based on cold water, warm water, and trout designated uses in 2-week to month temporal groupings.	T			*		
Fresh water, All classes (AA, A, B, C): NTE	T				83.0	
Fresh water, All classes (AA, A, B, C): Coldwater habitat, NTE outside thermal mixing zone	T				68.0	
Fresh water, All classes (AA, A, B, C): Max increase over ambient	D				4.0	
Sea Waters, All classes (SA, SB, SB1, SC): NTE	T				83.0	
Sea Waters, All classes (SA, SB, SB1, SC): Max increase over ambient (June-Sept)	D				1.6	
Sea Waters, All classes (SA, SB, SB1, SC): Max increase over ambient (Oct-June)	D				4.0	
Freshwater, free flowing: Max increase from ambient	D					5.0
Freshwater, free flowing: NTE	T					90.0
Shellfish harvesting, Class SA, Class SB: Max increase (based on weekly avg.) from ambient (fall, winter, spring)	D					4.0
Shellfish harvesting, Class SA, Class SB: Max increase (based on weekly avg.) from ambient (summer)	D					1.5
Lakes: Max increase from ambient	D					5.0
Lakes: NTE	T					90.0

Table 18. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for South Dakota, Tennessee, Texas, Utah, and Vermont. NTE = Not to exceed.

Description of Standard	Type of Standard	SD	TN	TX	UT	VT
Coldwater permanent fish propagation waters: NTE	T	65.0				
Coldwater marginal fish propagation waters: NTE	T	75.0				
Warmwater permanent fish propagation waters: NTE	T	80.0				
Warmwater semi permanent fish propagation waters: NTE	T	90.0				
Warmwater marginal fish propagation waters: NTE	T	90.0				
Domestic Water Supply: Max increase over ambient (i.e., upstream control point)	D		5.4			
Domestic Water Supply: NTE	T		86.9			
Domestic Water Supply: Max rate of change / h NTE	R		3.6			
Industrial Water Supply: Max increase over ambient (i.e., upstream control point)	D		5.4			
Industrial Water Supply: NTE	T		86.9			
Industrial Water Supply: Max rate of change / h NTE	R		3.6			
Fish and Aquatic Life: Max increase over ambient (i.e., upstream control point)	D		5.4			
Fish and Aquatic Life: NTE	T		86.9			
Fish and Aquatic Life: Max rate of change / h NTE	D		3.6			
Recognized Trout Waters: NTE	T		68.0			
Freshwater Streams: Max increase over ambient	D			5.0		
Freshwater Lakes and Impoundments: Max increase over ambient	D			3.0		
Tidal Rivers Reaches, Bay, Gulf Waters: Max increase over ambient	D			4.0		
Aquatic Wildlife, class 3A: NTE	T				68.0	
Aquatic Wildlife, class 3A: Max increase over ambient	D				3.6	
Aquatic Wildlife, class 3B: NTE	T				80.6	
Aquatic Wildlife, class 3B: Max increase over ambient	D				7.2	
Aquatic Wildlife, class 3C: NTE	T				80.6	
Aquatic Wildlife, class 3C: Max increase over ambient	D				7.2	
Cold water fish habitat: Max increase over ambient	D					1.0
Warm water fish habitat (Lakes, Ponds, Reservoirs): Max increase over ambient (Ambient >60F)	D					1.0
Warm water fish habitat (Lakes, Ponds, Reservoirs): Max increase over ambient (Ambient 50-60F)	D					2.0
Warm water fish habitat (Lakes, Ponds, Reservoirs): Max increase over ambient (Ambient <50F)	D					3.0
Warm water fish habitat (All other waters): Max increase over ambient (Ambient >60F)	D					1.0

Warm water fish habitat (All other waters): Max increase over ambient (Ambient 63-66F)	D					2.0
Warm water fish habitat (All other waters): Max increase over ambient (Ambient 59-62F)	D					3.0
Warm water fish habitat (All other waters): Max increase over ambient (Ambient 55-58F)	D					4.0
Warm water fish habitat (All other waters): Max increase over ambient (Ambient <50F)	D					5.0

Table 19. Specific description, type of standard (T = threshold, D = differential, and R = rate), and value (°F) for temperature standards for Virginia, Washington, West Virginia, Wisconsin, and Wyoming. NTE = Not to exceed. * = the reader is referred to the regulatory document because NTE and differential values exist for a multiple factor combinations (e.g., specific waterways, seasonality/temporal categories, and/or biological criteria) and are too numerous to list.

Description of Standard	Type of Standard	VA	WA	WV	WI	WY
Class III, Nontidal Waters: NTE	T	89.6				
Class IV, Mountainous Zones: NTE	T	87.8				
Class V, Stockable Trout Waters: NTE	T	69.8				
Class VI, Natural Trout Waters: NTE	T	68.0				
Class I-V & VII: Max increase over ambient	D	5.4				
Class VI, Natural Trout Waters: Max increase over ambient	D	1.8				
Char spawning and rearing: highest 7-day average of the daily maximum temperature (7-DADMax)	T		53.6			
Core summer salmonid habitat: Highest (7-DADMax)	T		60.8			
Salmonid spawning, rearing, and migration: Highest (7-DADMax)	T		63.5			
Salmonid rearing and migration ONLY: Highest (7-DADMax)	T		63.5			
Non-anadromous interior redband trout: Highest (7-DADMax)	T		64.4			
Indigenous warm water species: Highest (7-DADMax)	T		68.0			
Marine, extraordinary quality: highest 1-day maximum temperature (1-DMax)	T		55.4			
Marine, excellent quality: highest (1-DMax)	T		60.8			
Marine, good quality: highest (1-DMax)	T		66.2			
Marine, fair quality: highest (1-DMax)	T		71.6			
Aquatic life class B1, B4: NTE (May-Nov)	T			87.0		
Aquatic life class B1, B4: NTE (Dec-Apr)	T			73.0		
Aquatic life class B1, B4: Max increase over ambient	D			5.0		
Aquatic life class B1, B4 streams: Max increase over ambient	D			5.0		
Aquatic life class B1, B4 lakes and reservoirs: Max increase over ambient	D			3.0		
Kanawha River Main Stem: Max increase over ambient	D			5.0		
Kanawha River Main Stem: NTE	T			90.0		
Aquatic life class B2, selected lakes and reservoirs: Max increase over ambient	D			5.0		
Aquatic life class B2, selected lakes and reservoirs: NTE (May-Nov)	T			81.0		
Aquatic life class B2, selected lakes and reservoirs: NTE (Dec-Apr)	T			73.0		
Cold waters: Daily mean (Oct-Apr)	T			50.0		
Cold waters: Hourly max (Oct-Apr)	T			55.0		
Cold waters: Daily mean (Sept-May)	T			58.0		

Cold waters: Hourly max (Sept-May)	T			62.0		
Cold waters: Daily mean (Jun-Aug)	T			66.0		
Cold waters: Hourly max (Jun-Aug)	T			70.0		
Multiple NTE criteria based on month, temp categories, published ambient levels, sub-lethal criteria, and acute criteria. In addition, multiple similar tables with site specific sub lethal and acute criteria.	T				*	
Cold water fisheries, Class 1, 2AB, 2B: Max increase over ambient (when ambient temperatures >60F)	D					2.0
Warm water fisheries, Class 1, 2AB, 2B, 2C: Max increase over ambient (when ambient temperatures >60F)	D					4.0
Cold water stream fisheries, Class 1, 2AB, 2B: Max increase over max daily ambient temperature	D					2.0
Warm water stream fisheries, Class 1, 2AB, 2B: Max increase over max daily ambient temperature	D					4.0
Cold water stream fisheries, Class 1, 2AB, 2B: NTE	T					68.0
Warm water stream fisheries, Class 1, 2AB, 2B: NTE	T					86.0

Table 20. General categories of criteria and characteristics used for setting temperature standards in each of the fifty U.S. states (-- = not detected).

State	Seasonal/ Temporal Specific Criteria for Temperature	Designated Use Specific Criteria for Temperature	Regional/ Site Specific Criteria For Temperature	Organism/ Biology Specific Criteria for Temperature	Notes
Alabama	Y	Y	Y	Y	
Alaska	--	Y	--	Y	In aquaculture various life stages NTE 13-15 C.
Arizona	--	Y	Y	--	
Arkansas	--	--	Y	--	See Reg. 2.502 for waterbody specific criteria.
California	Y	Y	Y	--	
Colorado	--	Y	--	--	
Connecticut	--	Y	Y	--	
Delaware	--	Y	Y	--	For all waters the state mandates additional site-specific limitations.
Florida	Y	--	Y	--	
Georgia	--	Y	--	--	
Hawaii	--	--	Y	--	
Idaho	Y	Y	Y	Y	Very specific Bull Trout Temperature Criteria.
Illinois	Y	--	Y	--	
Indiana	Y	--	Y	--	
Iowa	Y	Y	Y	--	
Kansas	--	Y	--	--	Criteria for industrial cooling water recycling reservoirs will be on a case by case basis.
Kentucky	--	Y	--	--	Cabinet may determine allowable surface water temperatures on

					a site-specific basis utilizing available data.
Louisiana	--	--	Y	--	Site-specific maximum temperature values are presented in Table 3 of the Surface Water Quality Standards document.
Maine	--	--	Y	Y	Site-specific criteria may be established for temperature and substituted but must be no less protective of species indigenous to that area.
Maryland	--	Y	Y	Y	
Massachusetts	Y	Y	Y	--	
Michigan	--	Y	Y	Y	Water body specific criteria established for NTE temperature values based on monthly maximum temperatures. Also, edge of mixing zone standards for designated uses.
Minnesota	--	Y	Y	--	
Mississippi	Y	--	Y	--	
Missouri	Y	--	Y	--	Specific criteria for the Mississippi River for each month within three different River Zones (see table within Water

					Quality document).
Montana	--	Y	Y	--	Very specific temperature differential criteria: based on temperature ranges and site specific criteria.
Nebraska	--	Y	Y	--	
Nevada	Y	Y	Y	--	Very specific temperature criteria for individual water bodies that have variable NTEs, differentials, designated use categories, and seasonal definitions.
New Hampshire	--	Y	--	--	Class B waters temperature criteria is narrative from RSA 485-A:8, II, and V111.
New Jersey	Y	Y	--	--	
New Mexico	--	Y	Y	--	Max surface water temperatures are specified for specific water bodies.
New York	Y	--	Y	Y	
North Carolina	--	Y	Y	Y	
North Dakota	--	Y	Y	--	
Ohio	Y	--	Y	--	Multiple used designations and multiple site specific temperature criteria.
Oklahoma	--	Y	--	--	

Oregon	Y	--	Y	Y	
Pennsylvania	Y	Y	--	Y	Temperature differentials do not appear to be used. Three protected use categories (CWF, WWF, TSF) have individual NTE values for two-week blocks throughout the year.
Rhode Island	Y	Y	--	--	
South Carolina	Y	Y	Y	Y	
South Dakota	--	Y	--	--	
Tennessee	--	Y	--	Y	
Texas	Y	--	Y	--	
Utah	--	Y	--	--	
Vermont	--	Y	--	--	Temperature differentials in warm water are based on ambient temperature categories.
Virginia	--	Y	Y	Y	
Washington	--	--	Y	Y	
West Virginia	Y	Y	Y	--	
Wisconsin	Y	Y	Y		Multiple NTE criteria based on month, temp categories, published ambient levels, sub-lethal criteria, and acute criteria. In addition, multiple site-specific NTE criteria tables with acute and chronic levels for each month.
Wyoming	--	Y	--	--	

Table 21. General comments and narrative regarding mixing zones and temperature criteria or standards for each of the forty-nine U.S. states excluding Texas.

State	Mixing Zone Narrative for Thermal Discharges
Alabama	Mixing zones not addressed for thermal discharges
Alaska	Mixing zone procedures addressed (Pg. 42-47; 18 AAC 70.240), not specific for temperature but applies to all criteria
Arizona	Mixing zone procedures addressed (Pg. 25-26; R18-11-114), not specific for temperature but applies to all criteria
Arkansas	Mixing zone procedures addressed (Pg. 4-1 to 4-2; Reg. 2.404), not specific for temperature but applies to all criteria
California	Mixing zones not detected for thermal discharges within the document
Colorado	Detailed mixing zone procedures addressed for a variety of aquatic habitats (Pg. 24-27; 31.10), not specific for temperature but appears to apply to all criteria
Connecticut	Mixing zone methodology not detected in water quality standards documents
Delaware	Mixing zone procedures addressed (Pg. 34-36; Section 6). Temperature specific mixing zone size procedures discussed (Pg. 35; Section 6.4.2)
Florida	Discussion on thermal mixing zones can be found on Pg. 28-29 in the Surface Water Quality Standards document (62-302).
Georgia	Mixing zone approach described (#10 in document 391-3-6-.03 Water Use Classifications and Water Quality Standards), but not specifically for temperature.
Hawaii	Procedures for zones of mixing described generally for water quality standards (Section 11-54-9 of Chapter 54 (Water Quality Standards) of the Hawaii Administrative Rules). Specific thermal criteria described for zone of mixing: temp NTE 30C or exceed 3C above ambient, whichever is less, within 1 m of the bottom within a zone of mixing (Section 11-54-9, (6), (D)) [Pg. 54-72].
Idaho	Mixing zone policy described (Pg. 23-25, section 060. Mixing Zone Policy). Regarding temperature: shall not cause danger to beneficial uses and heat discharge cannot cause thermal shock, lethality, or loss of cold water refugia.
Illinois	Mixing zone policy described generally for standards (Section 302.102). No mixing zone information specific for temperature.
Indiana	Mixing zone guidelines described generally for standards (Section 327 IAC 2-1-4). No mixing zone information specific for temperature.
Iowa	Mixing zone guidelines described generally for standards (Section 61.2(4)) [Pg.3-6]. Temperature changes within the mixing zone for heat dissipation will not exceed the temperature criteria (Pg. 6).
Kansas	Mixing zone guidelines and approaches are dispersed throughout the states Surface Water Quality Standards document
Kentucky	Specifically states that all minimum criteria apply to mixing zones as well as surface waters.
Louisiana	Mixing zone policies described (Pg. 58 of the Environmental Regulatory Code)
Maine	Mixing zone policies and procedures not detected, likely a function of rules/laws as segmented documents on webpage
Maryland	Mixing zone policy and procedures described generally for standards (Section .05 Surface Water Mixing Zones; Pg. 84-87). No mixing zone information specific for temperature.

Massachusetts	Mixing zone policies described (Section 4.03, (2) in the Surface Water Quality Standards document). No specific information for temperature and the mixing zone.
Michigan	Edge of mixing zone specific monthly max temperatures for various use classifications (See Part 4. Water Quality Standards, Pg. 47-50). Mixing zone policies and procedures described (Part 4. Water Quality Standards, Pg. 47-50).
Minnesota	Mixing zone policy and procedures described generally for standards (Waters of the State; Pg. 23). No mixing zone information specific for temperature.
Mississippi	Mixing zone policy and procedures described generally for standards (Water Quality Criteria document, Pg. 4). No mixing zone information specific for temperature.
Missouri	Thermal mixing zones specifically addressed (Chap 7 Water Quality, Pg. 8). Thermal plume lengths and widths are determined on a case-by-case basis.
Montana	Mixing zone policies and procedures not detected
Nebraska	Thermal mixing zones briefly addressed (Chapter 2; section 010). Requirements for thermal mixing zones are defined on a site-by-site basis.
Nevada	Mixing zones not detected for thermal discharges
New Hampshire	Mixing zone policy and procedures described generally for standards (Code of Administrative Rules, Surface Water Quality Regulations, PART Env-Wq 1707 MIXING ZONES; Pg. 32). No language specific for temperature.
New Jersey	Mixing zone policy and procedures are described dispersed throughout the document (Surface Water Quality Standards, NJSA 58:10A-1). Specific language on thermal dissipation areas related to mixing zones was detected (Surface Water Quality Standards, NJSA 58:10A-1, Pg. 17).
New Mexico	Mixing zone policy and procedures described generally for standards (20.6.4 Standards document, Pg. 11-12). Language specific for temperature criteria not detected.
New York	Mixing zone policy and procedures described in detail for various aquatic habitats and generally for standards (Guidance document 1.3.1). No language specific for temperature standards.
North Carolina	Mixing zone policy and procedures described generally for standards. No language specific for temperature.
North Dakota	Mixing zone policy and procedures specifically described (Chapter 33-16-02.1 Standards of Quality for Waters of the State, Pg. 37-44). Methodology applicable to thermal waste, but specific language specific for temperature criteria not detected.
Ohio	Mixing zone policy and procedures described (State of Ohio Water Quality Standards, Section 3745-1-06). Separate thermal and non-thermal mixing zone policies.
Oklahoma	Mixing zone policy and procedures described generally for standards (OK Water Quality Standards, 785:45-5-26. Mixing zones and zones of passage, Pg. 27). No language specific for temperature.
Oregon	State has temperature-specific document entitled Temperature Water Quality Standard Implementation that contains specific information about mixing zones.
Pennsylvania	Mixing zone methodology not detected in water quality standards documents
Rhode Island	Specifically address thermal mixing zones with procedures/policy on cross-sectional area, volume, flow (Rhode Island, Water Quality Regulations, Pg. 14).
South Carolina	Mixing zone policies and procedures not detected

South Dakota	Mixing zone policy and procedures described in individual document (Mixing Zone and Dilution Implementation Procedures). No language specific for temperature standards.
Tennessee	Mixing zone policies and procedures minimally discussed in the General Water Quality Criteria document (Pg. 18).
Utah	Mixing zone policy and procedures described generally for standards (Utah Administrative Code, R317-2-5. Mixing Zones, Pg. 5-6). Methodology involving size and flow relative to receiving stream discussed. No language specific for temperature.
Vermont	Mixing zone policy and procedures described generally for standards (Vermont Water Quality Standards, Vt. Code R. 12 004 052). Language specific for temperature detected in the temperature standard narrative. Typical mixing zone (200 ft.) is not adequate for assimilation.
Virginia	Mixing zone policy and procedures described generally for standards (9 VAC 25-260 Virginia Water Quality Standards, Pg. 7-8). Language specific for temperature criteria not detected.
Washington	Mixing zone policies/rules for standards document was identified (Washington State Legislature WAC 173-201A-400). Language specific to temperature standard not detected in the document.
West Virginia	Individual document Water Quality Standards / Mixing Zones Implementation Guidance addresses mixing zones. Mention of temperature within the document is in reference to its modifying properties of other contaminants in which there are standards.
Wisconsin	Mixing zone policies/rules for standards was addressed (Water Quality Standards for Wisconsin Surface Waters, NR 102.05, (3)). Language specific to temperature standard not detected in the document.
Wyoming	Individual document Implementation Policies for Antidegradation, Mixing Zones, Turbidity, Use attainability analysis. Language specific for temperature criteria not detected.

Table 22. General comments and narrative regarding temperature criteria or standard exemptions or variances for each of the forty-nine U.S. states excluding Texas.

State	Exemption / Variance Narrative for Temperature Standards
Alabama	No thermal standards exemptions noted in document search
Alaska	Specific thermal exemptions procedures described (Pg. 30; 18 AAC 70.220)
Arizona	Exemption (variances) procedures described (Pg. 32; R18-11-122)
Arkansas	Procedures for site specific criteria and exemptions (variance) are described generally for all standards (Pg. 3-8 to 3-11)
California	No thermal standards exemptions noted in document search
Colorado	Exemptions only mentioned related to mixing zones.
Connecticut	Exemptions and/or permit variance methodology not detected in water quality standards documents
Delaware	Exemptions and/or permit variance methodology described (Pg. 39; Section 9). Specifically removal of designated uses and modification of water quality criteria.
Florida	Brief text on exemptions (Pg. 7, Surface Water Quality Standards document (62-302)), but not specific for thermal waste.
Georgia	Variances briefly described, but not specifically for temperature (Section 2, part (f) of the document 391-3-6-.03 Water use Classifications and Water Quality Standards
Hawaii	Exemptions and/or permit variance methodology not detected in water quality standards documents
Idaho	Variances from WQ Standards described (Pg. 160-161, section 260. Variances From Water Quality Standards). Regarding temperature: no specific description for thermal permit variances. Procedures for site-specific water quality standards described (Pg. 161-163, section 275).
Illinois	Exemptions and/or permit variance methodology for temperature not detected in water quality standards documents
Indiana	(1) Exemptions for antidegradation are described (Section 327 IAC 2-1.3-4). There are specific rules conditions described related to heat loadings (Section 327 IAC 2-1.3-4, Pg. 48) . (2) Permit variances for WQ Standards are described (Section 327 IAC 2-1-8.8), but specific information for temperature was not detected.
Iowa	Exemptions and/or permit variance methodology not detected in water quality standards documents
Kansas	Variances to WQ criteria may be accepted, but guidance is not provided (K.A.R. 28-16-28f, Pg. 2). No specific mention of temperature criteria variances.
Kentucky	Exceptions described under Section 10 of 401 KAR 10_031. No specific language regarding temperature.
Louisiana	Variances to WQ criteria may be accepted, but guidance is not provided (Pg. 48, Environmental Regulatory Code). No specific mention of temperature criteria variances.
Maine	Exemptions / permit variance procedures not detected, likely a function of rules/laws as segmented documents on webpage
Maryland	Exemptions and/or permit variance methodology not detected in water quality standards documents
Massachusetts	Variances for discharges described (Section 4.03, (4) in the Surface Water Quality Standards document). No specific information for permit variances for standards and specifically temperature.

Michigan	Water quality standard variances procedures described (Part 4. Water Quality Standards, Pg. 59-61). No specific mention of temperature criteria variances detected.
Minnesota	Variances procedures described (Water of the State, Pg. 22). No specific language regarding temperature.
Mississippi	Exceptions to designated uses which may affect standards are described (Water Quality Criteria document, Pg. 2-3). No specific language for temperature. No language related to permit variances detected.
Missouri	Variances for discharges and standards described (Chap 7 Water Quality, Pg. 21). No specific language for variances regarding temperature.
Montana	Exemptions and/or permit variance methodology for temperature not detected in water quality standards documents
Nebraska	Exemptions and/or permit variance methodology for temperature not detected in water quality standards document.
Nevada	Difficult to locate information on exemptions and variances for standards
New Hampshire	Procedures for determining alternative site specific criteria (Code of Administrative Rules, Surface Water Quality Regulations, PART Env-Wq 1704.02; Pg. 31). Information on exemptions and variances not detected.
New Jersey	Exemptions and/or permit variance methodology for temperature not detected in water quality standards documents
New Mexico	Language on exceptions for temperature criteria was detected (20.6.4 Standards document, section 20.6.4.11, I, Pg. 12).
New York	Policy on variances (site specific standards) documented (Guidance document 1.1.3). Temperature is described as one of several WQ parameters that may justify a variance if it influences a separate water quality stressor. However, no language specific for variances to temperature standards.
North Carolina	Exemptions and variances on water quality standards are granted on a case-by-case basis. No specific language related to temperature standards.
North Dakota	Policy and procedures for variances are described (Chapter 33-16-02.1 Standards of Quality for Waters of the State, Pg. 4). Specific language for variances on temperature standards not detected.
Ohio	Temporary variances are described (State of Ohio Water Quality Standards, Section 3745-1-01). No specific language on variances for temperature criteria.
Oklahoma	Processes for variances described (OK Water Quality Standards, 785:45-5-4. Applicability of narrative and numerical criteria, Pg. 11-13). No language specific for temperature.
Oregon	No thermal standards exemptions or variances detected.
Pennsylvania	Exceptions to water uses and water quality criteria may occur. Appear to be site-by-site basis, details not described.
Rhode Island	Policy/Procedure for variances (Rhode Island, Water Quality Regulations, Rule 20, Pg. 36-37). No specific language on variances for temperature standards noted.
South Carolina	Variances for discharges and standards described (R.61-68, Water Classifications and Standards, Pg. 16-17). No specific language for variances regarding temperature.
South Dakota	Exception related to temperature was detected in WQ standards document (section 74:51:01:31. Temperature change in fish life propagation waters). Exception to temperature standard may be granted if the discharge will not impair the designated beneficial use of fish life propagation.

Tennessee	Exemptions and/or permit variance methodology for standards was not detected in water quality standards documents
Utah	Exemptions and/or variance methodology for thermal standards not detected in the standards document.
Vermont	Exemptions and/or variance methodology for thermal standards not detected.
Virginia	Thermal variances specifically addressed (9 VAC 25-260 Virginia Water Quality Standards, Pg. 12).
Washington	Variance rules for standards document was identified (Washington State Legislature WAC 173-201A-420). Language specific to temperature standard not detected in the document.
West Virginia	Variances for discharges and standards described (Requirements Governing Water Quality Standards [47CSR2], Pg. 14). No specific language for variances regarding temperature standards.
Wisconsin	There appears to be a mechanism for variances to the water quality standards for temperature (Water Quality Standards for Wisconsin Surface Waters, NR 102.30).
Wyoming	Exemptions and/or variance methodology for thermal standards not detected in the Wyoming Surface Water Quality Standards document.

Table 23. General comments and narrative regarding implementation procedures or methods for temperature standards for each of the forty-nine U.S. states excluding Texas.

State	Narrative Statements on Implementation Procedures / Methods of Temperature Standards
Alabama	None identified in document.
Alaska	General, not specific for temperature (Pg. 27; 18 ACC 70.040).
Arizona	Not found in document.
Arkansas	Not found in document.
California	Not found in document.
Colorado	Detailed procedures described in the Temperature Criteria Methodology, Policy Statement 06-1, approved 2011.
Connecticut	Details of implementation procedures not detected in the documents.
Delaware	Details of implementation procedures not detected in the document.
Florida	Not found in the Surface Water Quality Standards document (62-302).
Georgia	Implementation procedures / methods for temperature criteria not detected in document.
Hawaii	Implementation procedures / methods for temperature criteria not detected in document.
Idaho	Implementation procedures / methods for temperature criteria not detected in document.
Illinois	Procedures for determining water quality criteria (Subpart F), but not specific for temperature.
Indiana	Implementation procedures / methods for temperature criteria not detected in document.
Iowa	Implementation procedures / methods are described (61.2(5)). Temperature criteria are specifically mentioned (Pg. 6)
Kansas	Implementation procedures for WQ standards described in the document Kansas Implementation Procedures - Surface Water Quality Standards (a supplement to the guidance document). No specific discussion on temperature detected.
Kentucky	Implementation methodology identified (401 KAR 10:030. Antidegradation policy implementation methodology).
Louisiana	Implementation procedures / methods for temperature criteria not detected in document.
Maine	Implementation procedures / methods for temperature criteria not detected in document, likely a function of rules/laws as segmented documents on webpage.
Maryland	Implementation procedures / methods for temperature criteria not detected in document.
Massachusetts	Implementation procedures / methods for temperature criteria not detected in document.
Michigan	Implementation procedures / methods for temperature criteria not detected in document.

Minnesota	Implementation procedures / methods for temperature criteria not detected in document.
Mississippi	Implementation procedures / methods for temperature criteria not detected in document.
Missouri	Implementation procedures / methods for temperature criteria not detected in document.
Montana	Implementation procedures / methods for temperature criteria not detected in document.
Nebraska	Implementation procedures / methods for temperature criteria not detected in document.
Nevada	Difficult to locate any information on implementation methods or procedures.
New Hampshire	Implementation procedures / methods for temperature criteria not detected in document.
New Jersey	Implementation procedures / methods for temperature criteria not detected in document.
New Mexico	Implementation procedures / methods described (20.6.4 Standards document, Pg. 7). Language specific for temperature criteria not detected.
New York	Procedures for deriving ambient water quality criteria described (Guidance document 1.1.5). No language specific for deriving temperature standards.
North Carolina	Implementation procedures / methods for temperature criteria not detected in document.
North Dakota	Implementation procedures / methods for temperature criteria not detected in document.
Ohio	Implementation of policies for phosphorous criteria, but none for temperature detected.
Oklahoma	Implementation of policies for phosphorous criteria, but none for temperature detected.
Oregon	State has a temperature-specific document entitled Temperature Water Quality Standard Implementation that contains specific implementation procedures.
Pennsylvania	Implementation guidance document for setting temperature criteria (Doc. #: 391-2000-017). Document details procedures for calculating effluents for NPDES permits.
Rhode Island	Implementation procedures / methods for temperature criteria not detected in document.
South Carolina	Implementation procedures / methods for temperature criteria not detected in document.
South Dakota	Implementation procedures / methods for temperature criteria not detected in document.
Tennessee	Implementation procedures / methods for temperature criteria not detected in document.
Utah	Implementation procedures / methods for temperature criteria not detected in document.

Vermont	Implementation procedures / methods for temperature criteria not detected in document.
Virginia	Implementation procedures / methods for temperature criteria not detected in document.
Washington	Implementation procedures for standards document was identified (Washington State Legislature WAC 173-201A-510). Language specific to temperature standard not detected in document.
West Virginia	Individual document Water Quality Standards / Mixing Zones Implementation Guidance addresses implementation. Language specific for temperature standards was not detected.
Wisconsin	Implementation procedures / methods for temperature criteria not detected in document.
Wyoming	Implementation procedures / methods for temperature criteria not detected in document.

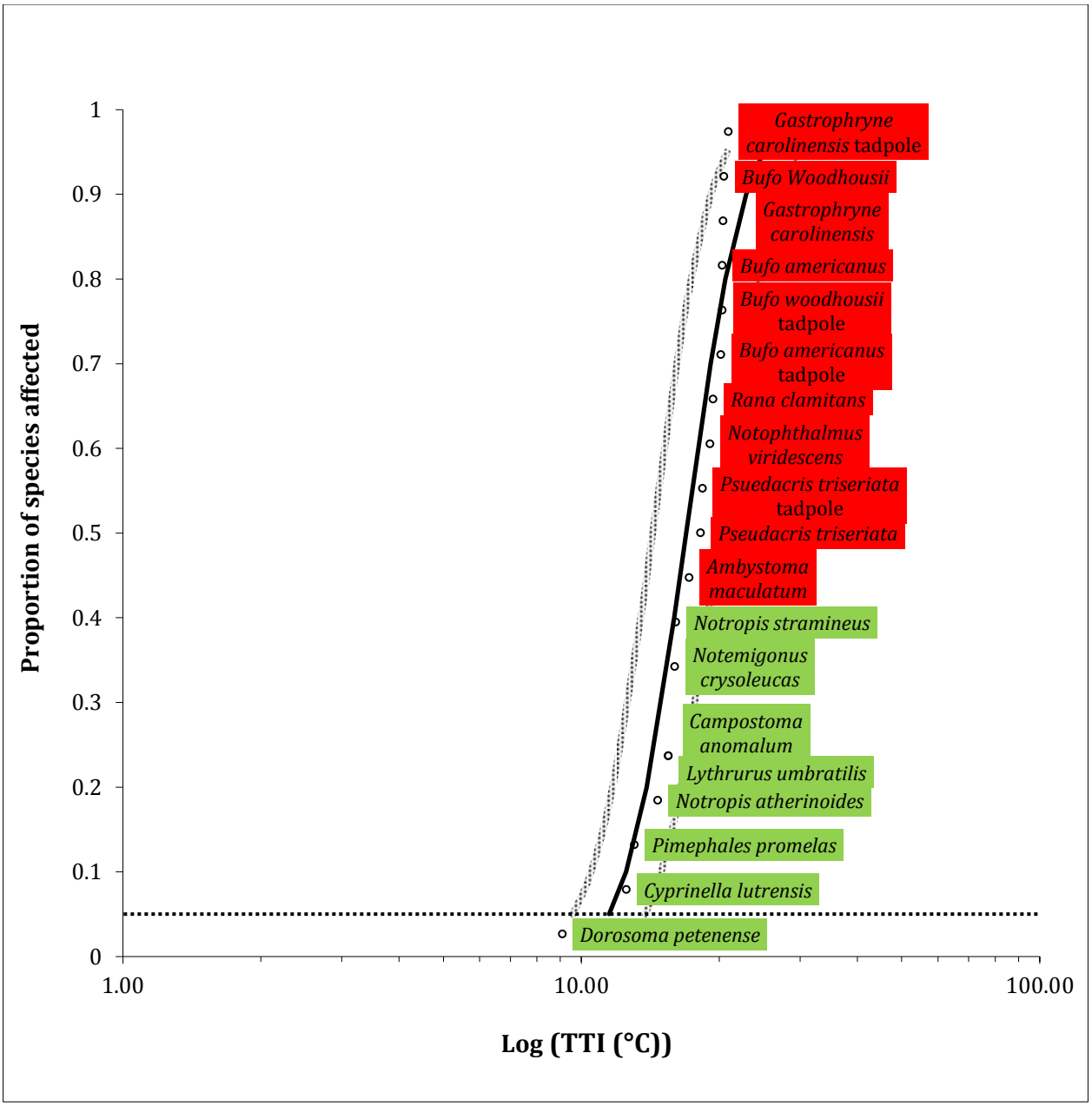

Figure 1. Species sensitivity distributions for temperature tolerance intervals of 19 aquatic vertebrate species. With an HTI5 value of 11.50 °C, *Dorosoma petenense* was outside the range of protection and the most sensitive species. The amphibian *Gastrophryne carolinensis* tadpole was be the least sensitive species.

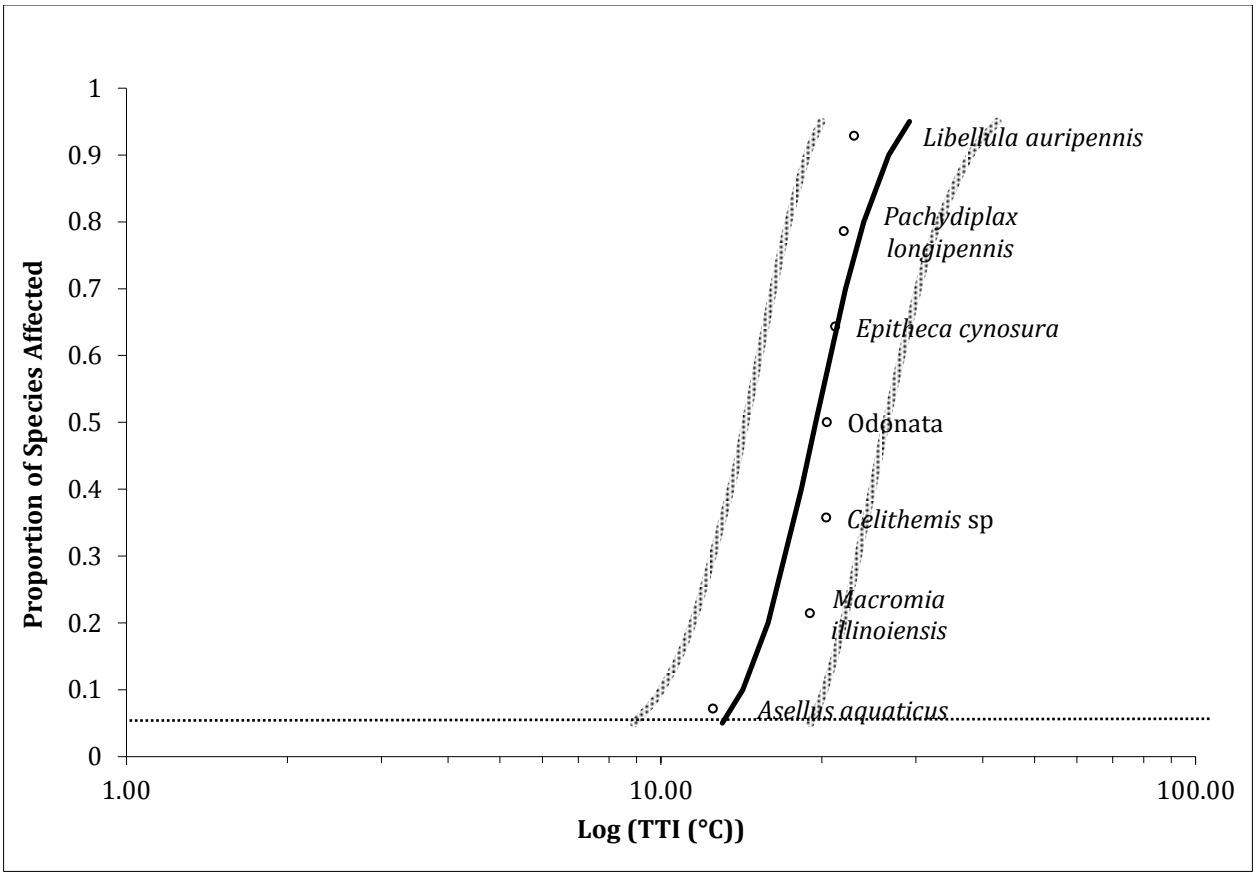

Figure 2. Species sensitivity distributions for temperature tolerance intervals of 7 aquatic invertebrate species. The HTI5 was 13.02 °C. *Asellus aquaticus* was the most sensitive species while *Libellula auripennis* was the least sensitive species.

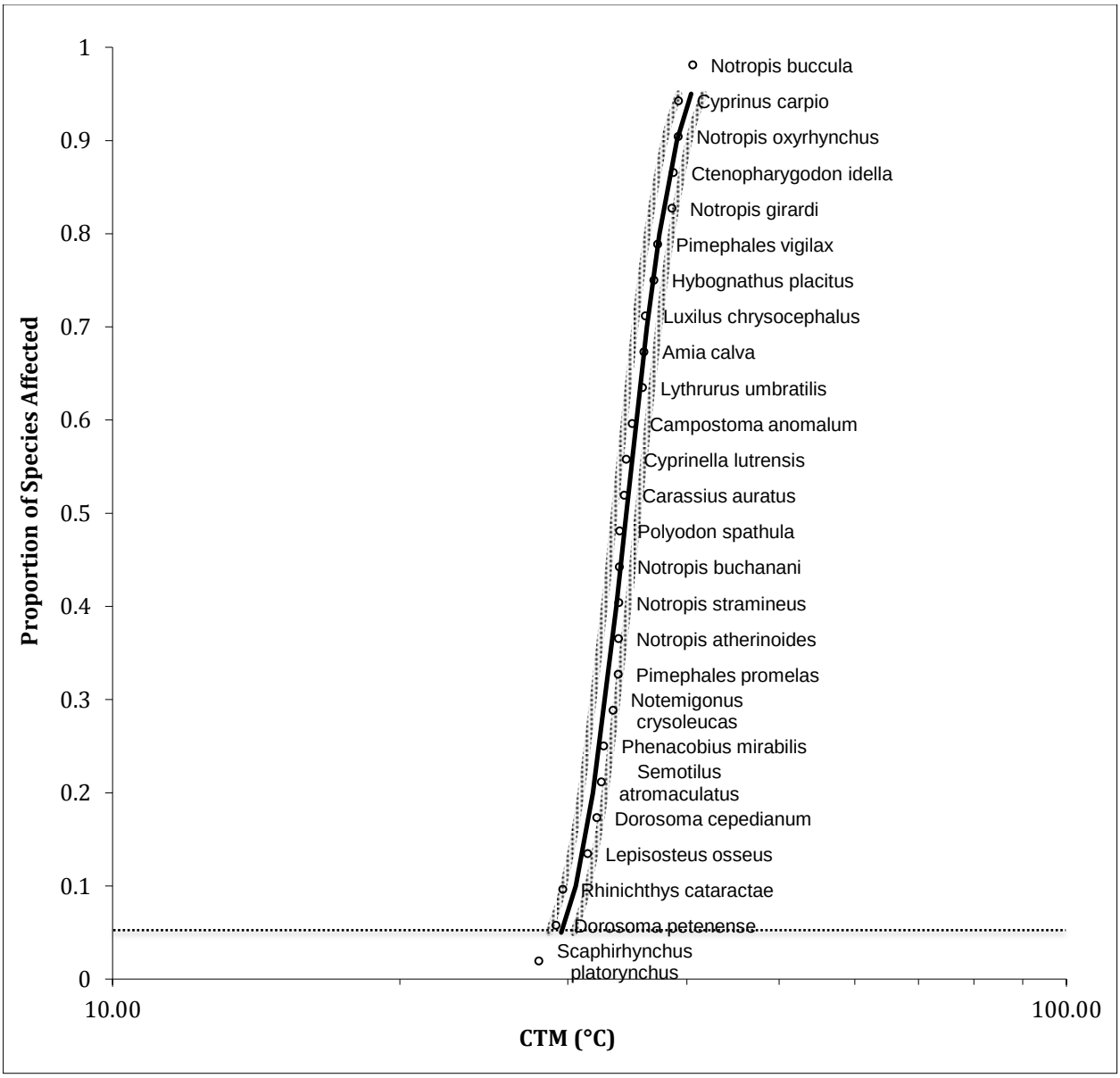

Figure 3. Species sensitivity distribution for the critical thermal maxima of 26 fish species. With an HTI5 value of 29.54 °C, *Scaphirhynchus platorynchus* was outside the range of protection and the most sensitive species. The least sensitive species was *Notropis buccula*.

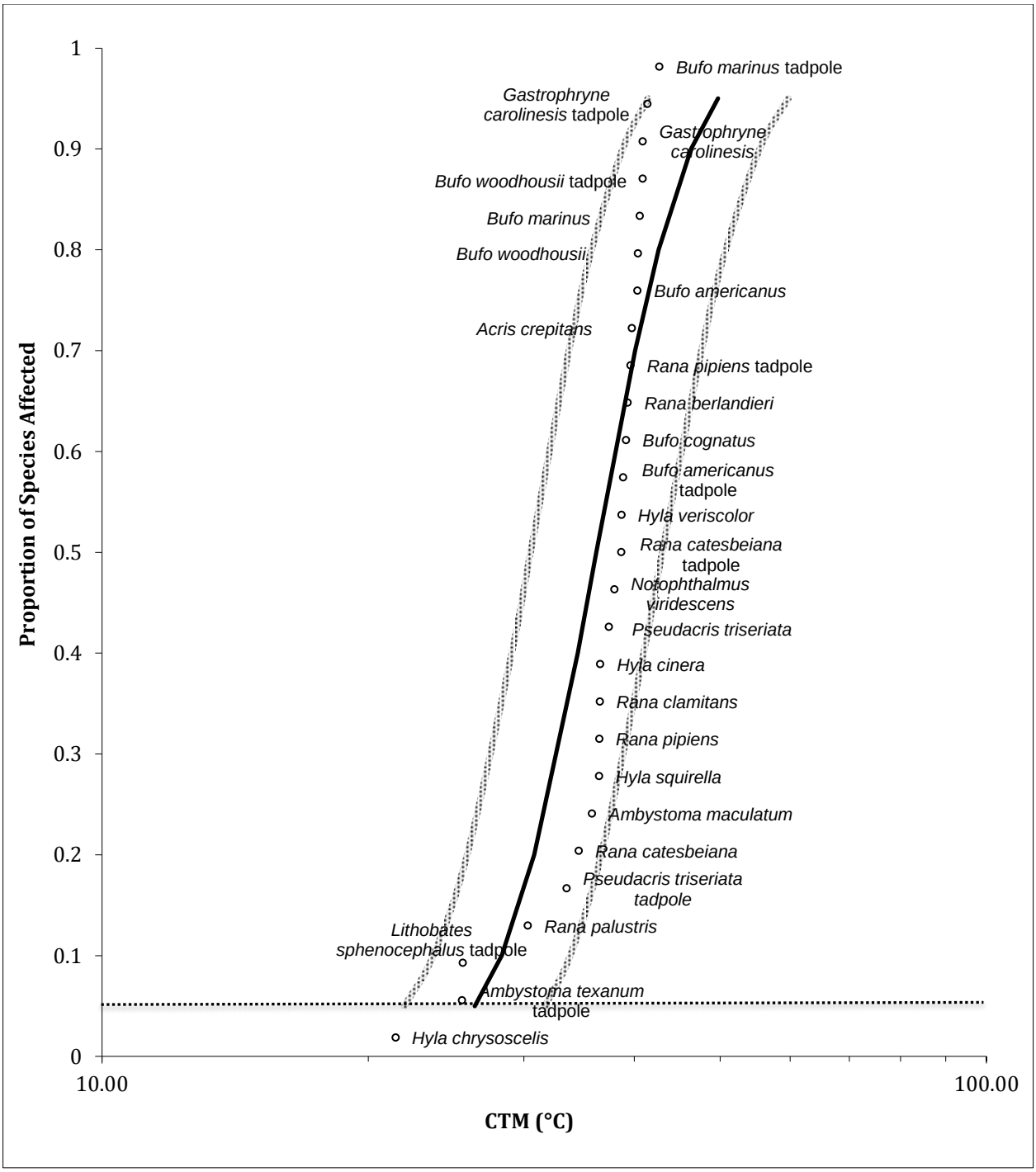

Figure 4. Species sensitivity distribution for the critical thermal maxima of 27 amphibian species. The HTI5 value was 26.39 °C, making *Hyla chrysoscelis* the most sensitive species and outside the range of protection. The least sensitive species was the *Bufo marinus* tadpole.

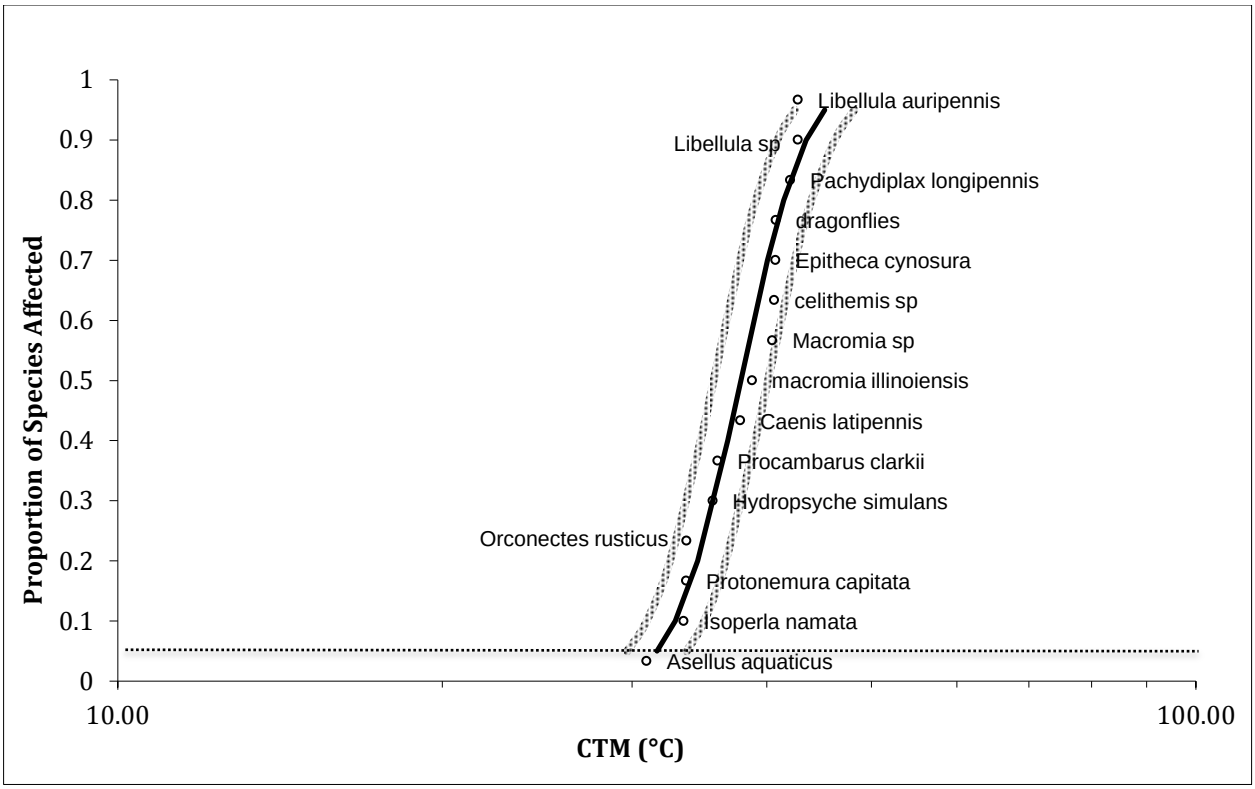

Figure 5. Species sensitivity distribution for the critical thermal maxima of 15 aquatic invertebrate species. The HTI5 value was 33.04 °C, making *Asellus aquaticus* the most sensitive species and outside the range of protection. The least sensitive species was the *Libellula auripennis*.

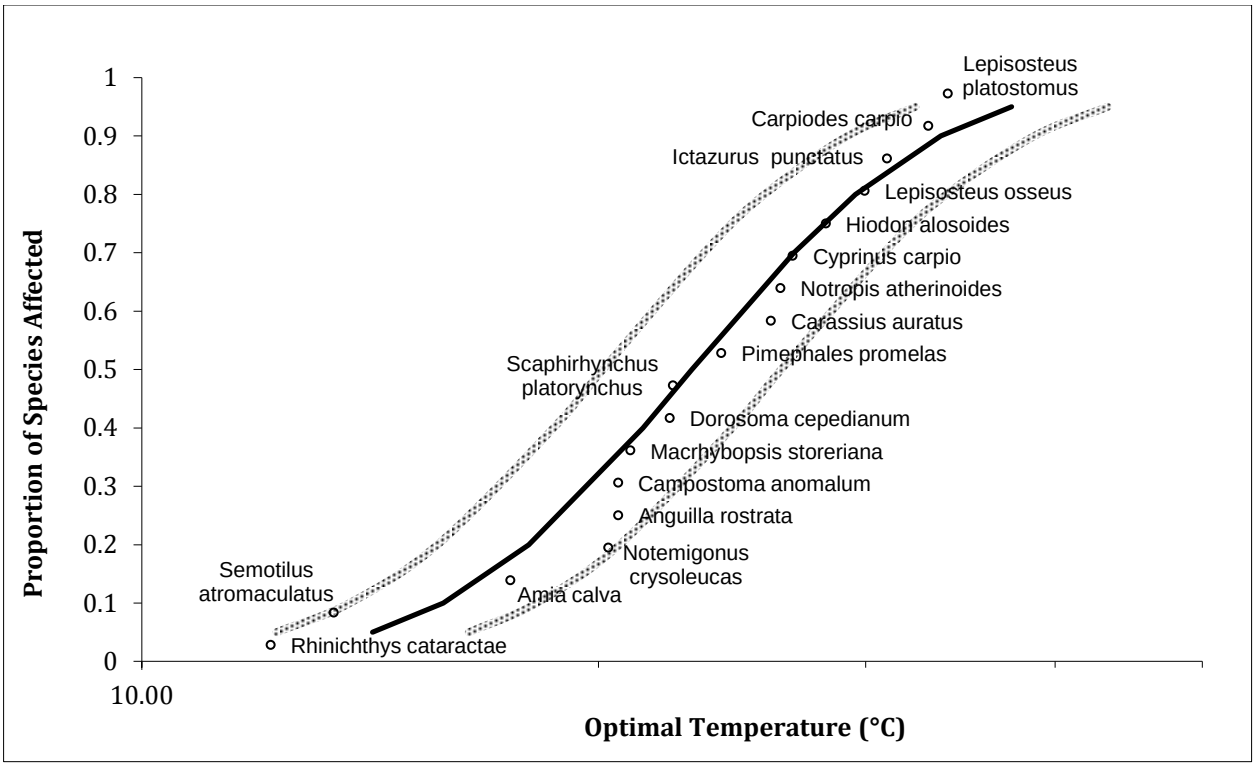

Figure 6. Species sensitivity distribution of optimal temperature for 18 fish species.

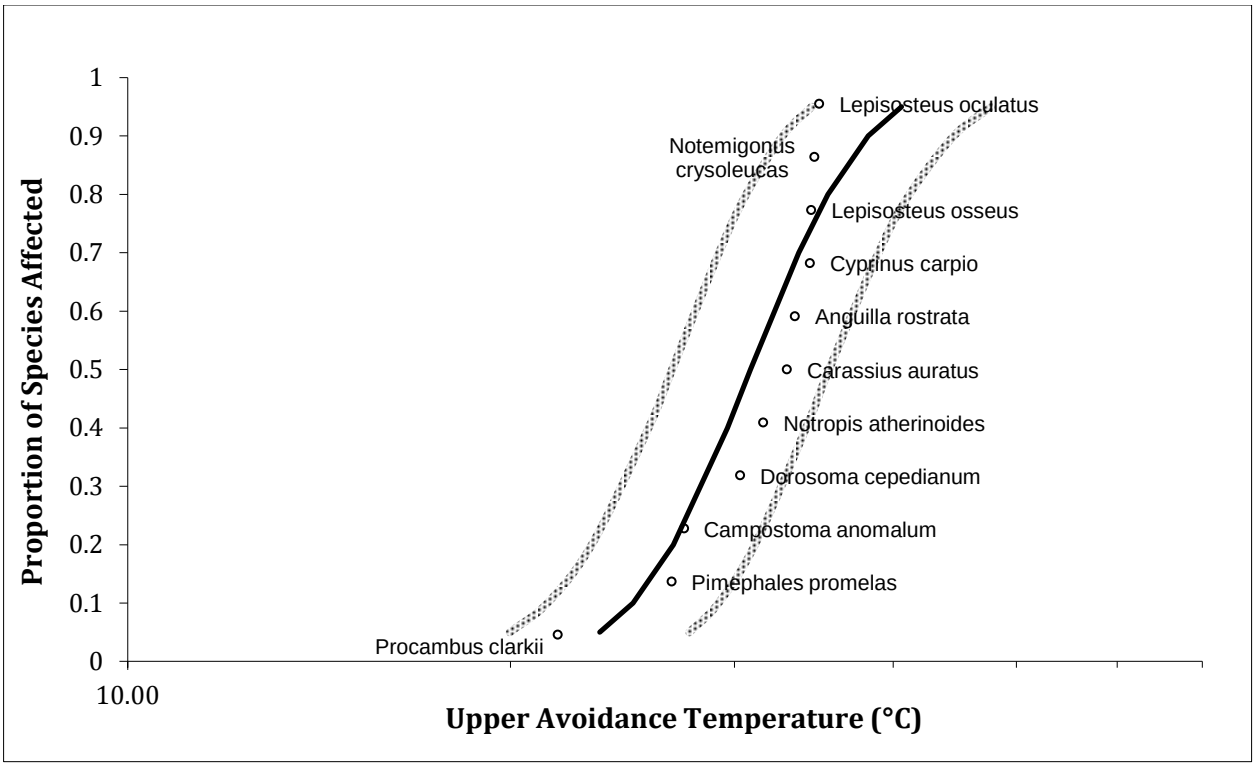

Figure 7. Species sensitivity distribution for upper avoidance temperature for 11 fish and aquatic invertebrate species.

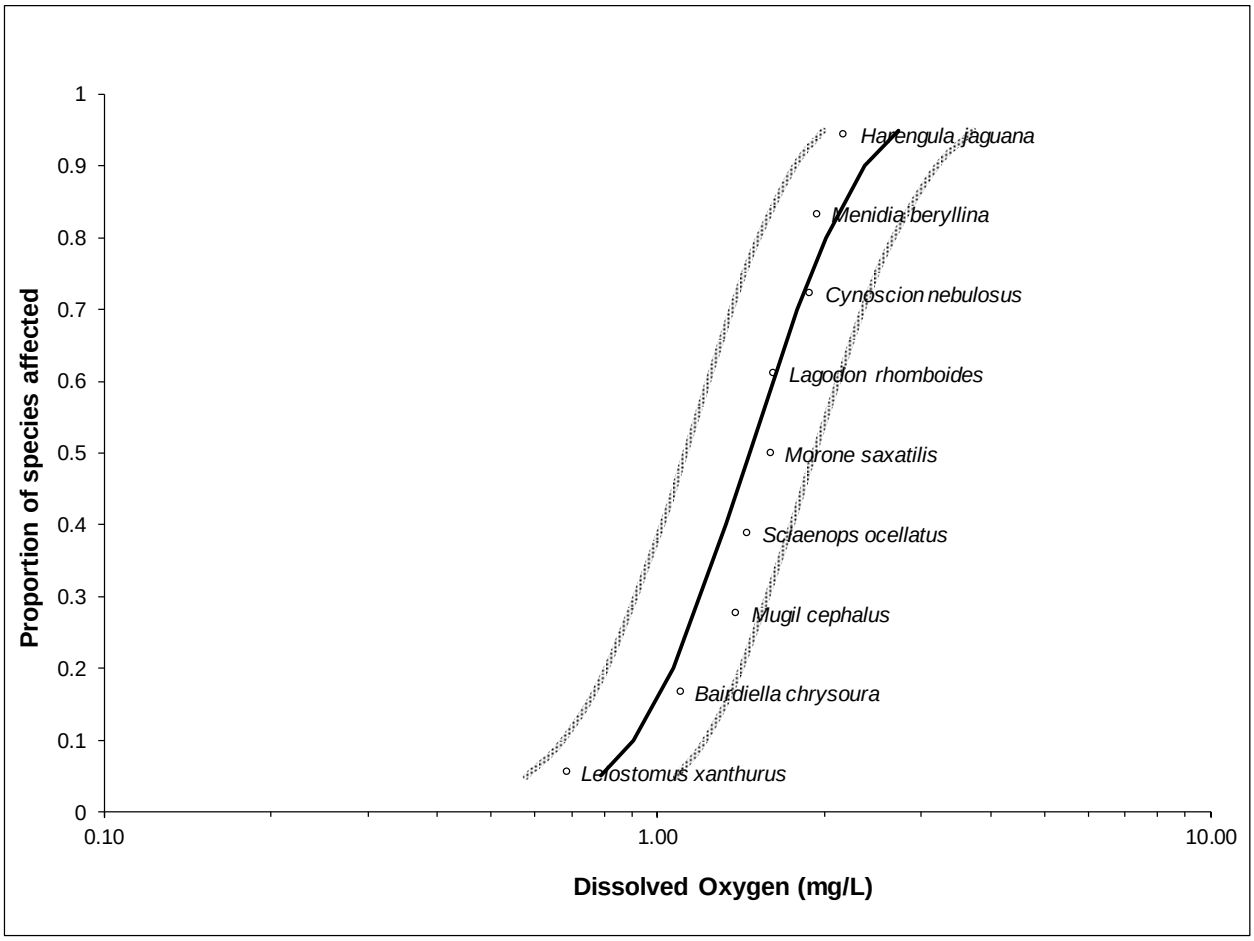

Figure 8. Species sensitivity distribution for dissolved oxygen (mg/L) toxicity to juvenile and adult fish species. Toxicity data are based on acute 24-96 h LC50s.

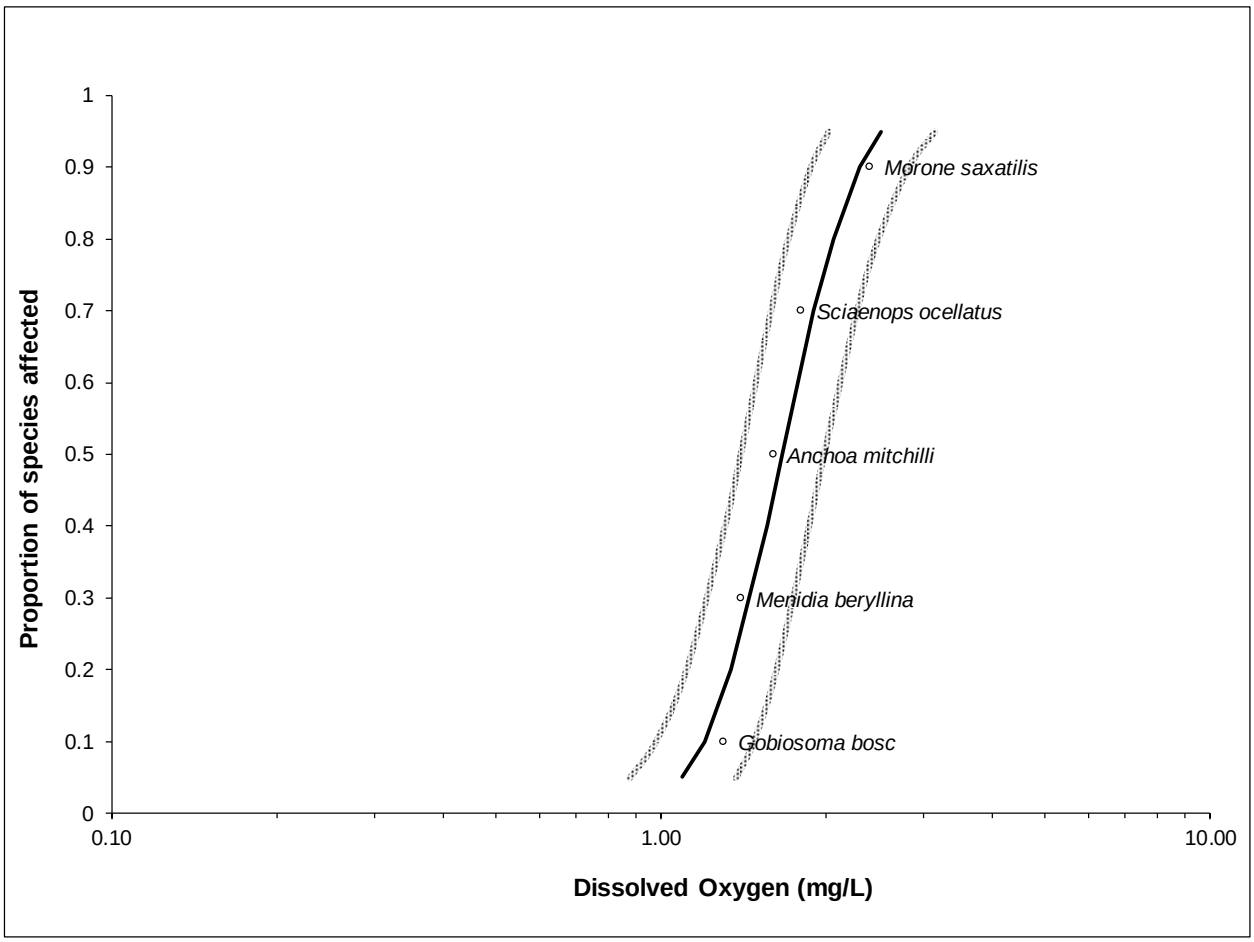

Figure 9. Species sensitivity distribution for dissolved oxygen (mg/L) toxicity to fish larvae. Toxicity data are based on acute 24-96 h LC50s.

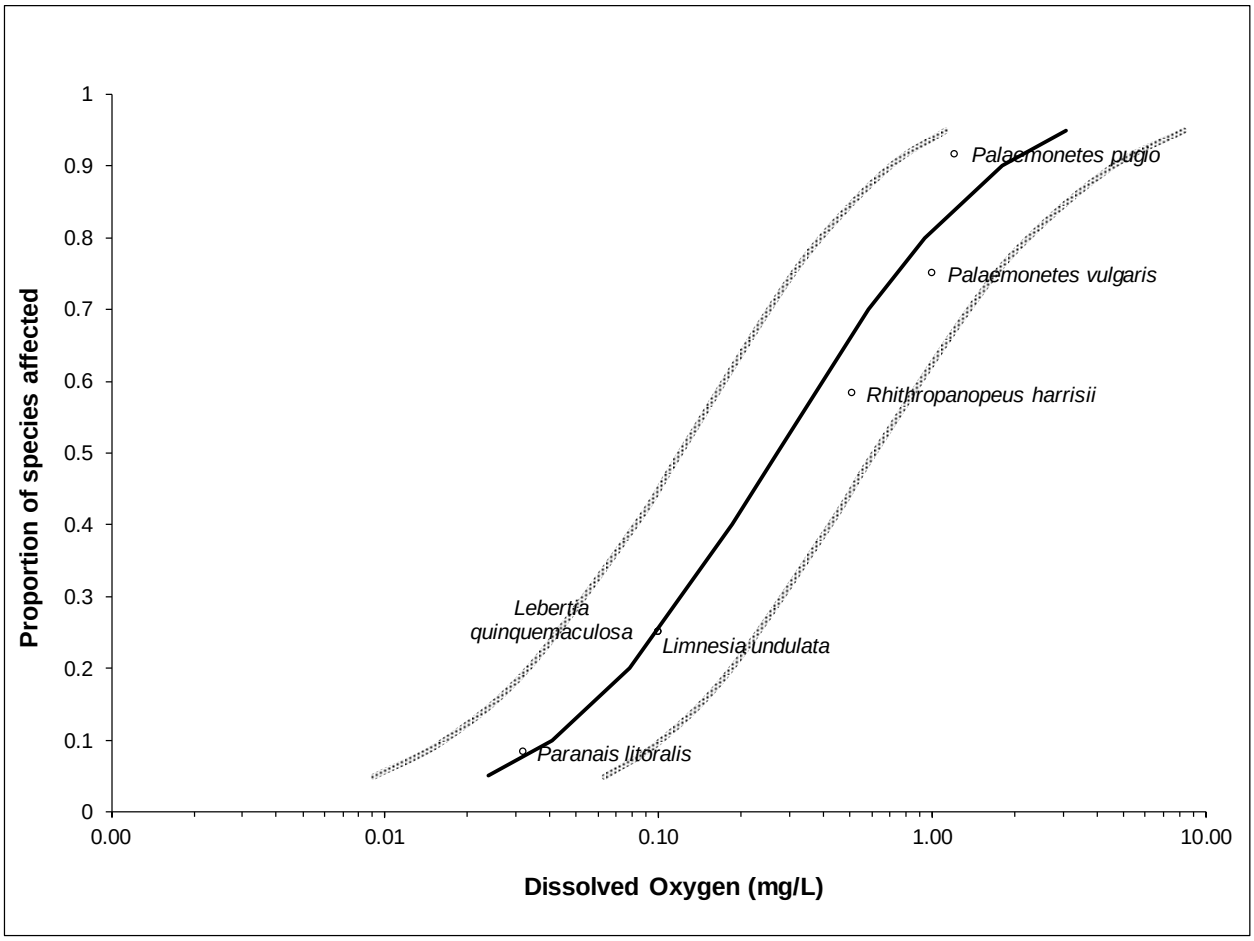

Figure 10. Species sensitivity distribution for dissolved oxygen (mg/L) toxicity to juvenile and adult invertebrates. Toxicity data are based on acute 24-96 h LC50s.

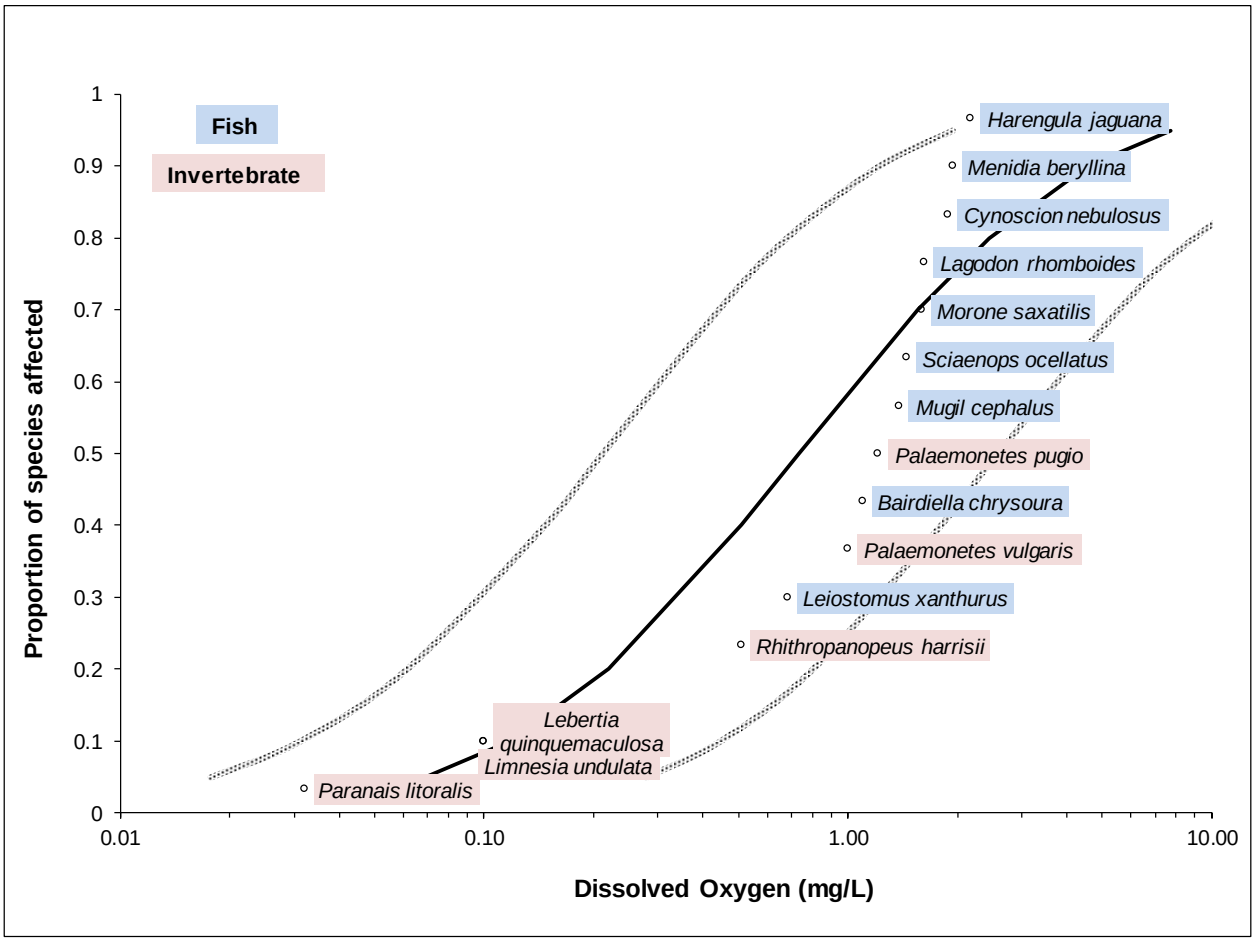

Figure 11. Species sensitivity distribution for dissolved oxygen (mg/L) toxicity to juvenile and adult fish and invertebrate species. Toxicity data are based on acute 24-96 h LC50s.

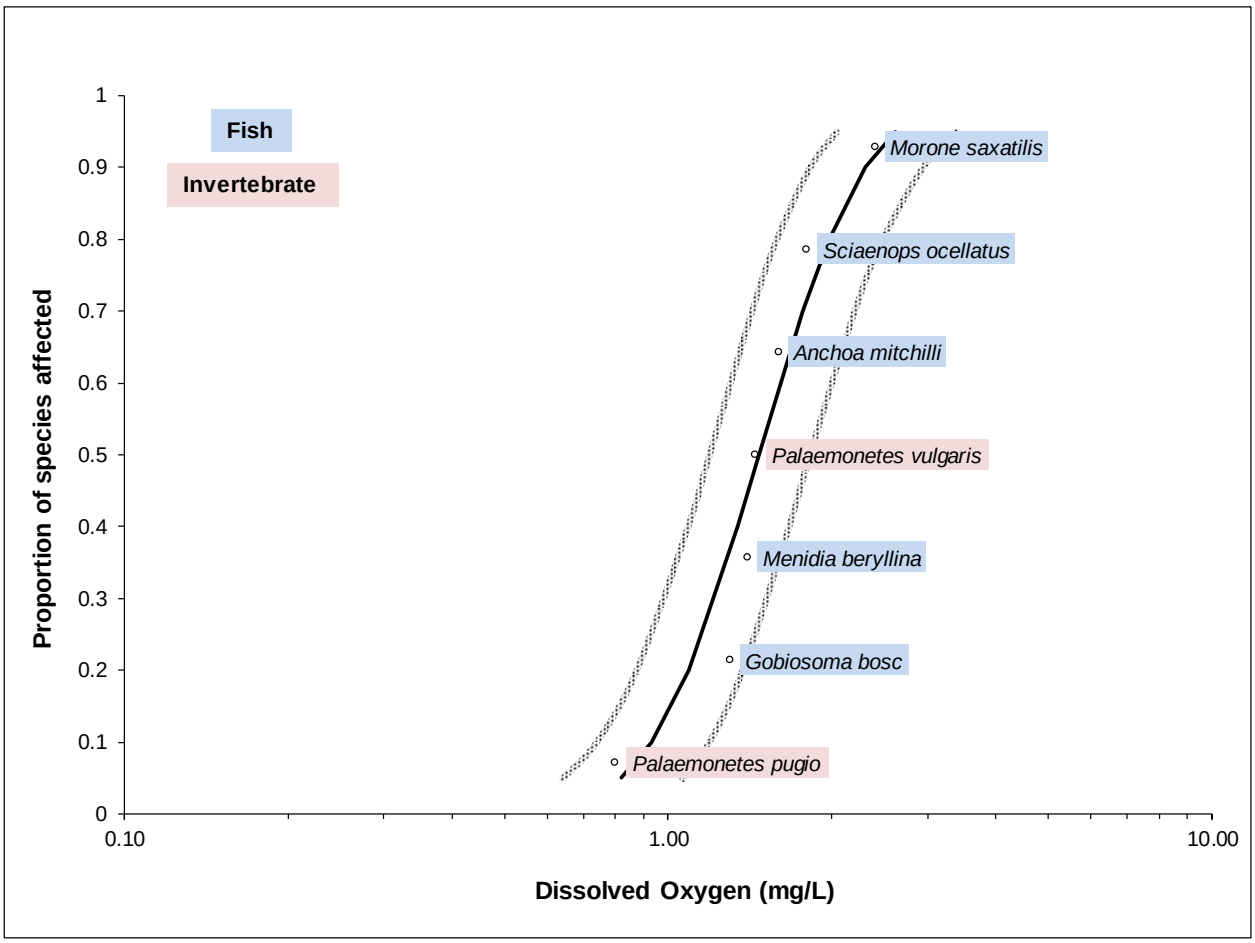

Figure 12. Species sensitivity distribution for dissolved oxygen (mg/L) toxicity to larval fish and invertebrate species. Toxicity data are based on acute 24-96 h LC50s.

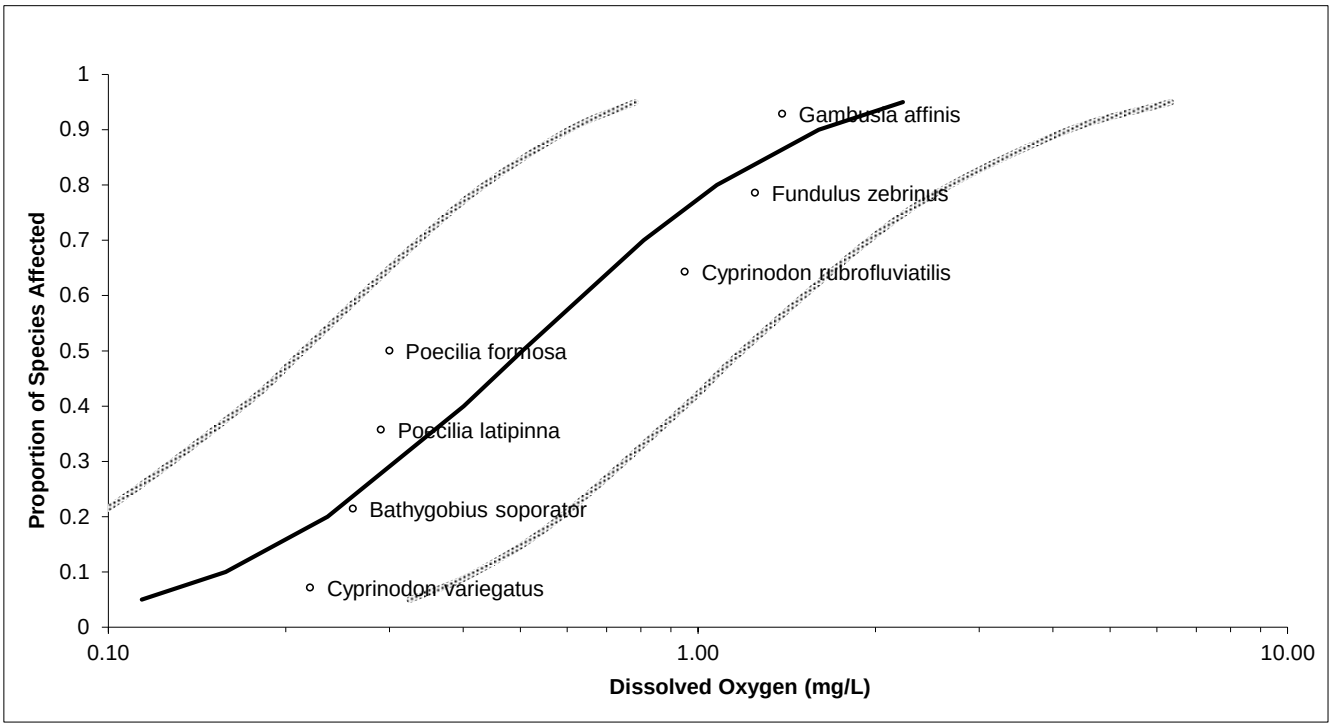

Figure 13. Species sensitivity distribution for dissolved oxygen (mg/L) effects on threshold for loss of equilibrium to juvenile fish species.

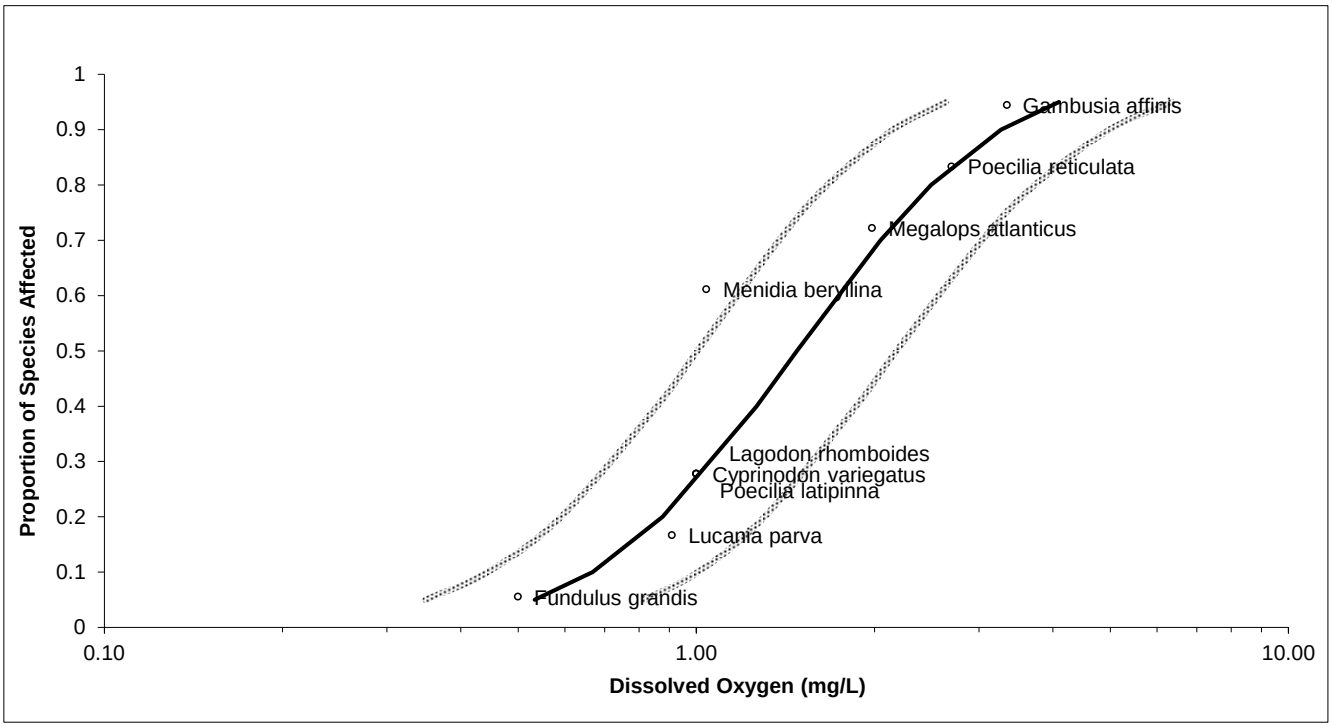

Figure 14. Species sensitivity distribution for dissolved oxygen (mg/L) effects on threshold for air-surface respiration in juvenile and adult fish species.