Temperature and Dissolved Oxygen Tolerance of Coolwater Fish Species in the Pacific Northwest (TD 37.1)

September 27, 2021

Introduction

This report summarizes literature on temperature and dissolved oxygen (DO) tolerances for various life stages of certain coolwater fish species.[1] Specifically, the objective of this literature review was to identify a suite of potential thermal and DO metrics that can be used to inform the development of protective thresholds for certain coolwater fish species in the Pacific Northwest. The data collected from this literature review could be considered in the future for Clean Water Act purposes such as in developing or evaluating water quality criteria to protect coolwater fish species.

Coolwater streams are considered to be intermediate between cold and warm waters. Variation in the definition of coolwater species can occur between states. For example, Oregon's rules include sturgeon as a coolwater species (OAR 340-041, *Water Quality Standards: Beneficial Uses, Policies, and Criteria for Oregon*), while Idaho identifies sturgeon as a coldwater species (IDAPA 58.01.02, *Water Quality Standards*). For consistency, the Pacific Northwest coolwater species designations found in Zaroban et al. (1999) were used to identify species of interest for this literature review.

Methods

Keyword Search

The keyword search strings were loosely based on the Cochrane PICO statement (Cochrane Community 2019) that the U.S. Environmental Protection Agency (EPA) has adapted for studies in the past (Bennett et al. 2017). This approach provides a structured methodology that identifies and limits results to studies that are scientifically defensible and answer the research question. The target population, stressor, comparator, and outcome were defined as follows for this literature review:

- **Target population:** Coolwater fish species that occur in the Pacific Northwest. The 56 coolwater fish presented in Zaroban et al. (1999) were used to represent this population and the green and white sturgeon were added as additional coolwater species of importance.
- **Stressors:** Increased water temperature; decreased DO levels.
- **Comparator:**
    - Laboratory studies: control treatments compared to exposure treatments, or fish exposed to different DO or temperature levels.
    - In situ: observed presence or absence of specified coolwater fish species for different life stages and certain temperature or DO levels.

[1] In 2017, EPA initiated but has not yet completed a similar temperature and dissolved oxygen literature review for cold water fish species in the Pacific Northwest. Similarly, in 2019, EPA funded a literature review to examine thermal tolerances of macroinvertebrates.

- **Outcome:**
  - Laboratory studies: observed changes in health outcomes that may include, but are not limited to, changes in growth, mortality, or successful incubation/hatching.
  - In situ studies: observed thermal or DO preferences based on observed presence/absence, avoidance, or mortality (i.e., observed mortality events).

These fields were used to develop a keyword search logic (see Appendix A) that was run in Web of Science for journal articles and Google for government reports. In addition to keyword searches, EPA provided citations and reference lists for consideration of relevance that were used to supplement searches.

Literature Search Inclusions and Exclusions

Inclusions and exclusions were defined to further refine the keyword searches. Filters for geographic location, publication type, and publication year were applied with the initial searches because the literature database allowed these filters.

- Geographically, no restrictions were applied. Despite the target area in the Pacific Northwest, it was decided that data associated with all occurrences of these fish species could provide relevant information.
- The publication type was initially limited to published, peer-reviewed journal articles. After additional consideration, the search was conducted again to collect federal and state reports with relevant information.
- The publication year was limited to 1990 through 2020. The cutoff date of 1990 was chosen to provide a boundary to an otherwise large volume of literature. This date captured all relevant literature that was initially identified. Additionally, there was interest in more recent information to ensure the latest science and understanding is represented in the reviewed information resources.

The initial journal article searches produced 571 journal article results. An additional 32 journal articles were provided by EPA for consideration. The report search produced 1,370 results. An additional 46 reports were provided by EPA for consideration.

Abstract Level Screening of Results

Additional inclusion and exclusion criteria were applied during an abstract level screen of literature results.

- Waterbody salinity type was restricted to freshwaters. Studies that discussed species in marine or brackish waters were excluded.
- Literature with secondary data was included in the literature assembled. For extraction, secondary data were pulled as presented in the literature and noted as secondary. If the

secondary data came from a source that predated the 1990 cutoff, the data were not included unless the citation was grouped with other citations dated 1990 or later.[2]

In addition to these additional inclusion and exclusion criteria, journal abstracts and report summaries were assessed for relevance to the literature review. After the screening of abstracts for potential relevance, approximately 304 journal articles and 57 reports were advanced to full-text review and data extraction, if the full-text review confirmed their relevance.

Full-text Screening and Data Extraction

Sources that were deemed potentially relevant during the abstract level screening of results were then assessed in full text. If the relevance of the full-text references was confirmed, data were extracted and entered into a data extraction spreadsheet with the fields shown in Table 1 below.

Table 1. Fields Included in the Data Extraction Spreadsheet

Extraction Category	Extraction Field
Study metadata	• Unique ID • Author • Year • Article title
Fish species	• Scientific name • Common name • Population: population where the fish were found • Life stage
Study design	• Study type: laboratory, in situ, model, review, other • Sample Size: number of fish studied

Stressors	• Temperature (°C)
	    ○ Mean temperature value
	    ○ Median temperature value
	    ○ Minimum temperature value
	    ○ Maximum temperature value
	    ○ Temperature standard deviation
	    ○ Temperature standard error
	• DO (mg/L)
	    ○ Mean DO value
	    ○ Median DO value
	    ○ Minimum DO value
	    ○ Maximum DO value
	    ○ DO standard deviation

[2] The decision to exclude data from secondary information that predated 1990 was made after extraction began. Instead of removing data from pre-1990 sources, it remains in the data extraction spreadsheet, but is largely omitted from tables in the results section of this summary report.

Extraction Category	Extraction Field
	○ DO standard error
Confounding variables	• For laboratory studies: ○ Feeding history ○ Acclimation temperature (°C) ○ Rate of change of temperature or DO levels ○ Control treatment presence ○ Comparison to control treatment • For in situ studies: ○ Monitoring replicates ○ Measurement details
Exposure	• Frequency of exposure • Duration of exposure • Time period • Experiment location
Outcome	• Endpoint • Effect • Effect type

Quality Checks

After the data extraction spreadsheet was populated, extractions in each cell were reviewed by independent, secondary researchers. Potential discrepancies were highlighted, and, in those cases, replacement information was suggested. Completed quality checks were returned to the original researcher to resolve any potential discrepancies that were identified and finalize the data extraction spreadsheet.

Results

Results from the literature review are summarized for each coolwater fish species below. Thresholds reported for temperature and dissolved oxygen (DO) are reported separately. Additionally, as information was available, it was further divided and presented by study type, with laboratory and review studies presented in the same table and other studies (e.g., in situ or model studies) presented together in a second table. For secondary data, the recorded study type reflects the source from which the information was extracted, which might not be the same study type as the primary data source.

We prioritized results for each species that were categorized by the authors or reviewers as optimal or preferred to more clearly display results that might be most important in informing temperature and DO thresholds. Those results categorized by the authors as 'optimal', 'preferred', 'consistent', 'suitable', or 'peak' were prioritized and placed at the top of each table, with the rows shaded and surrounded by a bold border. These results are also briefly summarized in the text preceding each set of tables. We used best professional judgement to prioritize more nuanced results by deciding whether the observed result was beneficial or protective for a species (e.g., "consistent growth rates", "99% survival rate", "good-growth temperature"). For DO, we relied on 'minima' results to define a value above which a species would be protected. 'Present' results were not prioritized because such results do not indicate an accurate threshold value above or below which a species would be absent or experience a detrimental effect. Additional details beyond those included in the following result tables (i.e., sample location and period, population details, and expanded notes on effects) for each information resource can be found in the accompanying data extraction spreadsheet.

No relevant temperature or DO data were found for the following species listed in Zaroban et al. (1999):

- *Catostomus rimiculus* (Klamath smallscale sucker)
- *Catostomus tahoensis* (Tahoe sucker)
- *Cottus aleuticus* (Coastrange sculpin)
- *Cottus marginatus* (Margined sculpin)
- *Cottus pitensis* (Pit sculpin)
- *Cottus tenuis* (Slender sculpin)
- *Lampetra ayresi* (River lamprey)
- *Lampetra minima* (Miller Lake lamprey)
- *Lampetra similis* (Klamath River lamprey)
- *Oregonichthys kalawatseti* (Umpqua chub)
- *Percopsis transmontane* (Sand roller)
- *Ptychocheilus umpquae* (Umpqua pikeminnow)
- *Rhinichthys evermanni* (Umpqua dace)
- *Richardsonius egregious* (Lahontan shiner)

Laboratory studies utilizing control treatment groups are considered the gold standard for determining the effect of temperature or DO thresholds because controls serve as a benchmark, accounting for other potentially confounding variables. The treatment group effects are compared to control groups to evaluate the magnitude of the effect. Whether a study used a control group in the study design is designated in the tables under the *study design considerations* column. Detailed notes on the control strategy can be found in the accompanying data extraction spreadsheet. In addition, other factors that can interact with the effect (e.g., feeding history, rate of change of temperature or DO levels, and acclimation temperatures) are presented in the *study design considerations* column when the information was available. The abbreviation “NA” was used when a study design consideration was not available (e.g., authors did not specify a feeding history during an experiment).

Other study types, such as observational and model studies, are included in the result tables because this information can provide context and multiple lines of evidence that further support the development of temperature and DO protective thresholds for various coolwater species and their respective life stages.

Acipenser medirostris (Green Sturgeon)

Optimal growth temperature ranges varied for each life stage of green sturgeon. In general, the optimal temperature for this species ranges from 9.5–24°C, but most of the reported results were between 13–19°C. Paragamiam and Wakkinen (2011) identified the highest probability of spawning to occur between

9.5– 9.9°C. Although no optimal DO concentrations were reported, 6.54 mg/L is the minimum DO concentration at which green sturgeon were observed in one study (Kelly et al. 2007).

Temperature

Laboratory and Review Studies

Table 2. *Acipenser medirostris* (Green Sturgeon) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Eggs/ embryos	Optimal incubation	13–15.5	Sample size: NA[3] Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Van Eenennaam et al. 2005 and Poytress et al. 2009, cited in Moser et al. 2016
Eggs/ embryos	Optimal incubation	14–17	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Van Eenennaam et al. 2005, cited in Moser et al. 2016
Eggs/ embryos	Optimal development and hatching success	14–16	Sample size: 9 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Rodgers et al. 2019
Embryo	Upper limit of thermal optima	17–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Van Eenennaam et al. 2005, cited in Erickson and Webb 2007
Larva	Survival rate: 99.5 ± 0.5%	16–17	Sample size: 4 Acclimation temperature: 17°C Rate of change: 1.5°C per hour Feeding history: NA Control: Yes	Laboratory	Werner et al. 2007
Larva	Optimal temperature range	18–20	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Rodgers et al. 2019
Embryos, larvae, and juveniles	Optimal temperature range	11–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Cech et al. 2000 in COSEWIC 2004, Mayfield and Cech 2004, Van Eenennaam et al. 2005 and Allen et al.

[3] NA stands for not available and is used throughout this document.

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
					2006, cited in NOAA 2009
Early life stages	Optimal temperature range	11 to 17–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Cech et al. 2000 in COSEWIC 2004 and Van Eenennaam et al. 2005, cited in NOAA 2009
Juvenile	Optimal temperature range	11–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Kaufman et al. 2007, cited in Moyle et al. 2015
Juvenile	Optimal temperature range	19–24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Reference not specified in Rodgers et al. 2019
Juvenile and adult	Consistent growth rates	15–19	Sample size: Six fish per tank, four replicate tanks for each of six treatments Acclimation temperature: 11, 15, and 19°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Preferred temperature	15.9	Sample size: 19 Acclimation temperature: 11°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Preferred temperature	15.7	Sample size: 11 Acclimation temperature: 19°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Preferred temperature	20.4	Sample size: 8 Acclimation temperature: 24°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Adult	Optimal temperature range	15–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Rodgers et al. 2019
Spawning and egg incubation	Optimal temperature range	14–16	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Van Eenennaam et al. 2005, cited in NOAA 2009

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Eggs/ embryos	Eggs/embryos observed	17.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Seesholtz et al. 2015, cited in Moser et al. 2016
Eggs/ embryos	Incubation	11–17.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Van Eenennaam et al. 2005 and Poytress et al. 2009, cited in Moser et al. 2016
Eggs/ embryos	Reduced hatching success	11	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Van Eenennaam et al. 2005 and Poytress et al. 2009, cited in Moser et al. 2016
Eggs/ embryos	Low hatching success	>20	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Van Eenennaam et al. 2005, cited in Moyle et al. 2015 and Moser et al. 2016
Eggs/ embryos	Upper thermal limit for survival	17–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Van Eenennaam et al. 2005, cited in Moyle et al. 2015
Eggs/ embryos	Suboptimal temperatures for development, with an increase in deformities	>17.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Reference not specified in Rodgers et al. 2019
Eggs/ embryos	Deformities and mortality	>22	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Mayfield and Cech 2004, Werner et al. 2007, and Van Eenennaam et al. 2005, cited in Moyle et al. 2015
Eggs/ embryos	100% Mortality	23–30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Van Eenennaam et al. 2005, cited in Rodgers et al. 2019
Larva	Increased incidence of deformities	>18	Sample size: 9 Acclimation temperature: NA Rate of change: NA	Review (meta-analysis)	Rodgers et al. 2019

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Larva	Percent with notochord abnormalities: 7.3%	16–17	Sample size: 4 Acclimation temperature: 17°C Rate of change: NA Feeding history: NA Control: Yes	Laboratory	Werner et al. 2007
Larva	Percent with notochord abnormalities: 16.5%	17–26	Sample size: 4 Acclimation temperature: 17 to 26°C Rate of change: 1.5°C per hour Feeding history: NA Control: Yes	Laboratory	Werner et al. 2007
Larva	Percent with notochord abnormalities: 25.2%	17–26	Sample size: 4 Acclimation temperature: 26°C Rate of change: 1.5°C per hour Feeding history: NA Control: Yes	Laboratory	Werner et al. 2007
Larva	Survival rate: 97.5%	17–26	Sample size: 4 Acclimation temperature: 26°C Rate of change: 1.5°C per hour Feeding history: NA Control: Yes	Laboratory	Werner et al. 2007
Larva	Survival rate: 97.3%	17–26	Sample size: 4 Acclimation temperature: 17 to 26°C Rate of change: 1.5°C per hour Feeding history: NA Control: Yes	Laboratory	Werner et al. 2007
Larva	Lethal temperature range	27–30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Rodgers et al. 2019
Larva	Suboptimal temperature range	20–27	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Rodgers et al. 2019
Juvenile	Ceased downstream migration	7–8	Sample size: 200 (began as fertilized embryos in lab) Acclimation temperature: NA Rate of change: NA Feeding history: Early larvae were fed a starter diet 6–8 times daily using a timed feeder and four times daily with live *Artemia nauplii* Control: NA	Laboratory	Kynard et al. 2005

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Ceased migration	<8	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Kynard et al. 2005, cited in Moser et al. 2016
Juvenile	Decreased swimming performance and increased cellular stress	>24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Allen et al. 2006, Werner et al. 2007, Linares-Casenave et al. 2013, and Wang et al. 2013, cited in Moser et al. 2016
Juvenile	Food consumption increased	19–24	Sample size: 8 tanks/treatment, 40 fish/tank, 3 treatments (stable at 19°C or 24°C, or cycling between 19–24°C) Acclimation temperature: 19°C Rate of change: 1°C per day Feeding history: Ad libitum rations of commercial diet Control: No	Laboratory	Allen et al. 2006
Juvenile	Activity level increased	19–24	Sample size: 8 tanks/treatment, 40 fish/tank, 3 treatments (stable at 19°C or 24°C, or cycling between 19–24°C) Acclimation temperature: 19°C Rate of change: 1°C per day Feeding history: Ad libitum rations of commercial diet Control: No	Laboratory	Allen et al. 2006
Juvenile	Increased metabolic rate with increased temperature within the reported range	11–24	Sample size: 20 Acclimation temperature: 11, 19, and 24°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile	Improved swimming performance observed with stable water temperatures	15	Sample size: 150 per treatment Acclimation temperature: 15°C Rate of change: Static or cycling change at rate of 0.9°C or 0.5°C per hour Feeding history: Ad libitum and fasted 24h prior to measurements Control: Yeses	Laboratory	Rodgers et al. 2018a

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Improved swimming performance at 11, 15, and 21°C when water temperature remained stable	11–21	Sample size: 153 per treatment, 5 treatment groups Acclimation temperature: 15 Rate of change: Static or 2°C per hour for different treatment groups Feeding history: Ad libitum and fasted 24h prior to measurements Control: Yes	Laboratory	Rodgers et al. 2018a
Juvenile	Improved growth	24	Sample size: 8 tanks/treatment, 40 fish/tank, 3 treatments (stable at 19°C or 24°C, or cycling between 19–24°C) Acclimation temperature: 19°C Rate of change: 1°C per day Feeding history: Ad libitum rations of commercial diet Control: No	Laboratory	Allen et al. 2006
Juvenile	Critical thermal maximum (endpoint was cessation of gill ventilation)	34.5	Sample size: 12 Acclimation temperature: 18.5 (±0.5)°C Rate of change: 0.3°C per min. Feeding history: 25% restriction group Control: Yes	Laboratory	Verhille et al. 2015
Juvenile	Critical thermal maximum (endpoint was cessation of gill ventilation)	34.1–34.5	Sample size: 12 Acclimation temperature: 18.5 (±0.5)°C Rate of change: 0.3°C per min. Feeding history: Three treatment groups (non-restricted at 2x optimal feeding rate, non-restricted group at optimal feeding, and 50% restriction group) Control: Yes	Laboratory	Verhille et al. 2015
Juvenile	Critical Thermal Maximum (endpoint was loss of equilibrium)	30.39–31.89	Sample size: 8–9 (per treatment) Acclimation temperature: Three treatment groups (13°C, 15°C, and 11°C, each for 1 hour) Rate of change: 0.3 C per min. Feeding history: Ad libitum and fasted 24h prior to measurements Control: Yes	Laboratory	Rodgers et al. 2018a

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Critical thermal maximum decreased as the magnitude of feed restriction increased (endpoint was loss of equilibrium)	28–33	Sample size: 840 per treatment group, 4 treatment groups Acclimation temperature: 18.6 Rate of change: 0.3°C per min. Feeding history: multiple treatments (0%, 12.5%, 25%, 50% restriction of optimal feeding rate) Control: Yes	Laboratory	Lee et al. 2016
Juvenile	Significantly elevated heat stroke protein in gills compared to control	28	Sample size: 9 Acclimation temperature: 18.6 Rate of change: direct transfer Feeding history: optimal feeding rate (non-restricted) Control: Yes	Laboratory	Lee et al. 2016
Juvenile and adult	Comparable critical swimming velocities for the 11°C and 19°C treatments	11–19	Sample size: 19, 11, and 8 for temperature treatment groups at 11, 19, and 24°C, respectively Acclimation temperature: 11, 19, and 24°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Decreased critical swimming velocities	24	Sample size: 19, 11, and 8 for temperature treatment groups at 11, 19, and 24°C, respectively Acclimation temperature: 11, 19, and 24°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Increased tail beat frequencies with increase of temperature from all acclimation temperatures	11–24	Sample size: 19, 11, and 8 for temperature treatment groups at 11, 19, and 24°C, respectively Acclimation temperature: 11, 19, and 24°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Increased food consumption rates	11–15	Sample size: Six fish per tank, four replicate tanks for each of six treatments Acclimation temperature: 11, 15, and 19°C Rate of change: 1°C per day	Laboratory	Mayfield and Cech 2004

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: No		
Juvenile and adult	Comparable food consumption in the 15°C and 19°C treatment groups	15–19	Sample size: Six fish per tank, four replicate tanks for each of six treatments Acclimation temperature: 11, 15, and 19°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Food conversion efficiency higher at 15°C than at 11°C at 50% rations	11–15	Sample size: 36 Acclimation temperature: 11, 15, and 19°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Increases in ration level significantly decreased food conversion efficiencies in the 15°C and 19°C treatments	15–19	Sample size: 36 Acclimation temperature: 11, 15, and 19°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Increased growth rates among fish held at 15°C than among those held at 11°C	11–15	Sample size: Six fish per tank, four replicate tanks for each of six treatments Acclimation temperature: 11, 15, and 19°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Increase in metabolic rate	19–24	Sample size: 19, 11, and 8 for temperature treatment groups at 11, 19, and 24°C, respectively Acclimation temperature: 11, 19, and 24°C Rate of change: 1°C per day Feeding history: NA Control: No	Laboratory	Mayfield and Cech 2004
Juvenile and adult	Maximum temperature for transporting between initial holding tank	25	Sample size: 19, 11, and 8 for temperature treatment groups at 11, 19, and 24°C, respectively Acclimation temperature: 11, 19, and 24°C Rate of change: 1°C per day	Laboratory	Mayfield and Cech 2004

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
	and testing tank		Feeding history: NA Control: No		
Adult	Suboptimal temperature range	19–24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Rodgers et al. 2019
Spawning and egg incubation	Present	11–17	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Van Eenennaam et al. 2005, cited in NOAA 2009
Not specified	Reduced growth	>19	Sample size: 8 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Rodgers et al. 2019
Not specified	Growth (expression of heat shock protein)	16–19	Sample size: 11 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review (meta-analysis)	Rodgers et al. 2019
Not specified	Branchial ventilation ceased	33.7–34.2	Sample size: 6 Acclimation temperature: 18 Rate of change: 0.3 °C per min. Feeding history: NA Control: Yes	Laboratory	Sardella et al. 2008
Not specified	Hematocrit[4] %: 40.1	18–34.2	Sample size: 6 Acclimation temperature: 18 Rate of change: NA Feeding history: NA Control: Yes	Laboratory	Sardella et al. 2008
Not specified	Plasma osmolality:[5] 90.1	18–34.2	Sample size: 6 Acclimation temperature: 18 Rate of change: NA Feeding history: NA Control: Yes	Laboratory	Sardella et al. 2008

[4] The amount of red blood cells in circulation.
[5] Measures the amount of dissolved substances in the blood.

In Situ, Model, or Other Publication Types

Table 3. ***Acipenser medirostris*** **(Green Sturgeon) Temperature Data from In Situ, Model, or Other Publication Types**

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Adult	Maximized growth potential	16 and 18	Sample size: NA Feeding history: Feeding at 50% and 75–100% maximum theoretical daily consumption rate, respectively	Model	Borin et al. 2017
Spawning	Highest observed probability of spawning	9.5–9.9	Sample size: NA	In situ	Paragamiam and Wakkinen 2011
Juvenile	Fast growth	18–23	Sample size: NA	Other (biological opinion)	NMFS 2015c, cited in USFWS 2015
Juvenile	Present	14–17.9	Sample size: NA	In situ	USFWS 2017
Juvenile	Present	9.1–22	Sample size: 29	In situ	USGS 2017
Juvenile and adult	Present	11.9–21.9	Sample size: 60	In situ	Moser and Lindley 2007
Adult	Present	14.5–20.8	Sample size: 6	In situ	Kelly et al. 2007
Adult (inferred)	Present	15–23	Sample size: 19	In situ	Erickson et al. 2002
Adult (inferred)	Outbound migration	10–13	Sample size: 19	In situ	Erickson et al. 2002
Spawning	Present	8–14	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Other (Federal Register)[6]	Deng 2000, cited in NOAA 2006
Spawning and adult	Upstream migration observed	8.3–16.2	Sample size: 103 tagged, actual sample size for temperature unclear	In situ	Erickson and Webb 2007
Spawning and adult	Spawning migration initiated	8.8–16.4	Sample size: 103 tagged, actual sample size for temperature unclear	In situ	Erickson and Webb 2007
Spawning and adult	Present (ripe for spawning)	9.7–18.0	Sample size: 103 tagged, actual sample size for temperature unclear	In situ	Erickson and Webb 2007
Not specified	Present	14.5–20.8	Sample size: NA	In situ	USGS 2017

[6] *Threatened Status for Southern Distinct Population Segment of North American Green Sturgeon*, Federal Register, April 7, 2006, 71:17757.

Dissolved Oxygen

Laboratory and Review Studies

Table 4. *Acipenser medirostris* (Green Sturgeon) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Juvenile and adult	Minimum of the observed range	6.54	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Kelly et al. 2007 and Moser and Lindley 2007, cited in NOAA 2009

In Situ, Model, or Other Publication Types

Table 5. *Acipenser medirostris* (Green Sturgeon) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Juvenile and adult	DO concentration in which fish were observed	6.54–8.89	Sample Size: 6 Temperature: NA	In situ	Kelly et al. 2007

Acipenser transmontanus (White Sturgeon)

Most of the optimal temperatures reported for white sturgeon pertain to juveniles and adult spawning. Bevelhimer (2002) found that white sturgeon that occupy waterbodies with moderate temperatures (8-19°C) tend to reproduce earlier, have increased egg production, and greater reproductive frequency than waterbodies that have larger yearly temperature fluctuations. Multiple sources estimated peak spawning to occur between 10–18°C. Lepla and Chandler (2001, cited in Idaho Power Company 2003) reported a broad range of temperatures suitable for egg incubation (6–20°C), and similarly, Hillman et al. (1999) cited multiple sources that indicated juvenile growth to be optimal between 15–25°C. However, multiple sources reported stress or decreased survival effects at temperatures greater than 20°C, especially in the egg, larval, and juvenile life stages. No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 6. *Acipenser transmontanus* (White Sturgeon) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Eggs/ embryos	Suitable for incubation	6–20	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Lepla and Chandler 2001, cited in Idaho Power Company 2003
Juvenile	Present (optimal temperature)	14.8–18.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Perrin et al. 1999, cited in Roberge et al. 2002
Juvenile	Optimum growth	15–25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Hillman et al. 1999
Spawning	Peak spawning occurs	12–16	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Wang et al. 1985 and Parsley et al. 1993, cited in Idaho Power Company 2003
Spawning	Peak spawning occurs	12–17.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Lepla and Chandler 2001, cited in Idaho Power Company 2003
Spawning	Peak spawning occurs	14	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Parsley et al. 1993, cited in Roberge et al. 2002
Spawning	Peak spawning occurs	14	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	McCabe and Tracy 1994, cited in Moyle et al. 2015
Spawning	Optimal spawning	10–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Hanson et al. 1992 and Parsley et al. 1993 cited in Jones et al. 2013.

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Optimum temperature range	15–25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Hillman et al. 1999
Eggs/ embryos	Upper lethal temperature	20–21	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Hillman et al. 1999
Larva	Present	14.8–18.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Perrin et al. 1999, cited in Roberge et al. 2002.
Juvenile	Appearance of stress[7]	23	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Idaho Power Company 2003
Juvenile	Stress and increased oxygen consumption	>19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Geist et al. 2005, cited in Israel et al. 2009
Juvenile	Critical thermal maximum did not change with feed restriction (endpoint was loss of equilibrium)	31–32.5	Sample size: 840 Acclimation temperature: 18.6°C Rate of change: 0.3°C per min. Feeding history: multiple treatments (0%, 12.5%, 25%, 50% restriction of optimal feeding rate) Control: Yes	Laboratory	Lee et al. 2016
Juvenile	Stress indicated by significantly elevated heat shock protein in mucus compared to control	28	Sample size: 9 Acclimation temperature: 18.6°C Rate of change: Direct transfer Feeding history: optimal feeding rate Control: Yes	Laboratory	Lee et al. 2016

[7] Additional detail was not available in the source.

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Reduced growth compared to 18°C treatment group	11	Sample size: 600 Acclimation temperature: 11 or 18°C Rate of change: 2°C per day Feeding history: 100% or 40% optimal feed rate Control: Yes	Laboratory	Rodgers et al. 2018b
Juvenile	Critical thermal maximum	30.7	Sample size: 9–11 per treatment Acclimation temperature: 18 Rate of change: 0.3°C per min. Feeding history: 100% or 40% optimal feed rate Control: Yes	Laboratory	Rodgers et al. 2018b
Juvenile	Critical thermal maximum	28.6	Sample size: 9–11 per treatment Acclimation temperature: 18 Rate of change: 0.3°C per min. Feeding history: 100% or 40% optimal feed rate Control: Yes	Laboratory	Rodgers et al. 2018b
Adult	Present	0–25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Hillman et al. 1999
Adult	Males initiate migration	5.5–12.1	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Cannings and Ptolemy 1998, Parsley et al. 1993, and Perrin et al. 1999, cited in Roberge et al. 2002
Adult	Females initiate migration	6.6–10.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Cannings and Ptolemy 1998, Parsley et al. 1993, and Perrin et al. 1999, cited in Roberge et al. 2002
Spawning	High incidence of ovarian regression	10–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Webb et al. 1999 and Webb et al. 2001, cited in Jones et al. 2013
Spawning	Inhibited ovulation and oocyte development	18–20	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Webb et al. 1999 and Linares-Casenave et al. 2002, cited in Moyle et al. 2015

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Spawning	Present	8.5–12	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Paragamian et al. 2001, cited in Roberge et al. 2002
Spawning	Present	14.8–18.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Perrin et al. 1999, cited in Roberge et al. 2002
Spawning	Present	15.5–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	R.L.&L. Environmental Services 1996, cited in Roberge et al. 2002
Spawning	Present	10–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Parsely et al. 1993 and Perrin et al. 1999, cited in Roberge et al. 2002
Spawning	Successful spawning	<18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Webb et al. 1999 and Linares-Casenave et al. 2002, cited in Moyle et al. 2015
Spawning	Spawning occurs	8–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	McCabe and Tracy 1994, cited in Moyle et al. 2015
Not specified	Growth rate: 2.2%	23	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Hung et al. 1993, cited in Mayfield and Cech 2004
Not specified	Growth rate: 1.9%	26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Hung et al. 1994, cited in Mayfield and Cech 2004

In Situ, Model, or Other Publication Types

Table 7. *Acipenser transmontanus* (White Sturgeon) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Adult	Earlier reproduction[8], increased egg production, and greater reproductive frequency within given temperature range	8–19	Sample size: NA	Model	Bevelhimer 2002
Spawning	Peak spawning activity	12–16	Sample size: NA	In situ	Idaho Power Company 2003
Eggs/ embryos	98% Mortality rate	≥18	Sample size: 132	Other (Conservation Plan)	Anders and Beckman 1995, cited in Jones et al. 2013.
Eggs/ embryos	Egg mortality	13–17	Sample size: NA	Other (Conservation Plan)	Anders and Beckman 1995, cited in Jones et al. 2013.
Eggs/ embryos	Lower hatch success	>18	Sample size: NA	Other (Conservation Plan)	R.L.&L. Environmental Services 1997, cited in Jones et al. 2013.
Larva	Present	17–18.6	Sample size: 4	In situ	Idaho Power Company 2003
Juvenile and adult	Present	8–24.2	Sample size: NA	In situ	Idaho Power Company 2003
Juvenile and adult	Loss of weight	>19 to 24	Sample size: NA	Model	Bevelhimer 2002
Adult (inferred)	Present	10–22	Sample size: NA	In situ	Lepla and Chandler 1995, cited in Sullivan et al. 2003
Adult	Lethal temperature	28	Sample size: NA	Model	Sullivan et al. 2003

[8] Earlier reproduction (age at first spawning) increases the overall lifetime egg production.

Dissolved Oxygen

Laboratory and Review Studies

Table 8. *Acipenser transmontanus* (White Sturgeon) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L, % air saturation, or Torr)	Study design considerations	Study type	Reference
Young-of-year	Higher forced maximum metabolic rate compared to the 100% DO treatment groups.	80%	Sample size: 308 Temperature: 16 or 14°C (3 trials) Rate of change: reduced 0.5°C per day Feeding history: changing proportion of shrimp and bloodworm; 100% bloodworm Control: Yes	Laboratory	Yoon et al. 2019
Young-of-year	Decreased oxygen consumption rate (MO_2) during hypoxia[9]	Moderately hypoxic (PO_2= 80 ± 5.0 mmHg)[10]	Sample size: 250 Temperature: 10, 16, 20°C Rate of change: <1°C 48 h Feeding history: ad libitum; starvation for 24 hr prior to experiment Control: Yes	Laboratory	Crocker and Cech 1997
Young-of-year	Lower energy density at 100% DO than 80% DO	80–100%	Sample size: 308 Temperature: 16 or 14°C Rate of change: reduced 0.5°C per day Feeding history: changing proportion of shrimp and bloodworm; 100% bloodworm Control: Yes	Laboratory	Yoon et al. 2019
Young-of-year	No seasonal effects on hepatosomatic index among 80% DO and 100% DO treatments	80–100%	Sample size: 308 Temperature: 16 or 14°C Rate of change: reduced 0.5°C per	Laboratory	Yoon et al. 2019

[9] MO_2 – measure of oxygen consumption
[10] PO_2 – units of Torr – a measure of partial pressure of oxygen

Attachment #8: White Sturgeon Literature Review

Life stage	DO consideration (effect)	DO value (mg/L, % air saturation, or Torr)	Study design considerations	Study type	Reference
			day Feeding history: changing proportion of shrimp and bloodworm; 100% bloodworm Control: Yes		
Young-of-year	Increased mortality at low temperatures compared to 100% DO treatment groups	80%	Sample size: 308 Temperature: 16 or 14°C Rate of change: reduced 0.5°C per day Feeding history: changing proportion of shrimp and bloodworm; 100% bloodworm Control: Yes	Laboratory	Yoon et al. 2019
Juvenile	Mean swimming activity (cm/h) decreased significantly during hypoxia (mean decrease: 78%, range: 65–88%).	Moderate hypoxic (PO_2 = 80 ± 5.0 mmHg)	Sample size: 250 Temperature: 10, 16, 20°C Rate of change: <1°C 48 h Feeding history: ad libitum; starvation for 24h prior to experiment Control: Yes	Laboratory	Crocker and Cech 1997
Juvenile	Decreased oxygen consumption rate, swimming activity, and growth/food consumption under moderate hypoxic stress	Hypoxia: 58% air saturation	Sample size: NA Temperature: 15, 20, and 25 °C Rate of change: NA Feeding history: ad libitum, fasted 24h prior to treatment Control: Yes	Laboratory	Cech and Crocker 2002

In Situ, Model, or Other Publication Types

Table 9. *Acipenser transmontanus* (White Sturgeon) Dissolved Oxygen Data from In Situ, Model, and Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Juvenile	Present	7.3–15.1	Sample Size: NA Temperature: NA	In situ	Idaho Power Company 2003
Adult	Present	8–16	Sample Size: NA Temperature: 10-22°C	In situ	Lepla and Chandler 1995 in Sullivan et al. 2003
Adult	Absent	<6	Sample Size: 4 Temperature: 10-22°C	In situ	Lepla and Chandler 1995 in Sullivan et al. 2003
Adult	Mortality	<1	Sample Size: 28 available Temperature: 25–26°C	In situ	Idaho Power Company 2003

Acrocheilus alutaceus (Chiselmouth)

The preferred temperature of chiselmouth is greater than 20°C (Wydoski and Whitney 1979 and Rosenfeld et al. 2000, cited in Roberge et al. 2002) yet peak spawning is estimated to occur at a lower temperature between 13–18°C (Gray and Dauble 2001). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 10. *Acrocheilus alutaceus* (Chiselmouth) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Juvenile and adult	Preferred temperature	>20	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Rosenfeld et al. 2000 and Wydoski and Whitney 1979, cited in Roberge et al. 2002

In Situ, Model, or Other Publication Types

Table 11. *Acrocheilus alutaceus* (Chiselmouth) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
		Optimal and preferred values			
Spawning	Peak spawning	13–18	Sample size: NA	In situ	Gray and Dauble 2001
Juvenile and adult	Present	19.6–22.9	Sample size: 20 sites with automatic temp loggers, fish captured at 14 of 50 total sites.	In situ	Rosenfeld et al. 1998
Spawning	Present	10–16	Sample size: NA	In situ	Gray and Dauble 2001
Spawning	Spawning initiated	15	Sample size: NA	In situ	Gray and Dauble 2001
Not specified	Present (peak summer temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Present	11–25	Sample size: NA	In situ	Ebersole 2001
Not specified	Present (maximum temperature range recorded)	20–26	Sample size: 53	Model	Rosenfeld et al. 2001
Not specified	Present (average maximum summer temperature)	21.2	Sample size: 14 (of 48 sites)	Model[11]	Porter et al. 2000
Not specified	Absent (average maximum summer temperature)	19.4	Sample size: 34 (of 48 sites)	Model[11]	Porter et al. 2000

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

[11] Authors developed logistic regression models using a combination of map-based features (e.g., watershed gradient, drainage area) and data collected in the field (e.g., bankfull width, stream temperature) to determine the level of information necessary to reliably predict fish species distributions. The models correctly classified presence and absence 85 percent of the time for this species.

In Situ, Model, or Other Publication Types

Table 12. *Acrocheilus alutaceus* (Chiselmouth) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	78%	Sample Size: NA Temperature: 25°C	In situ	Waite and Carpenter 2000

Alosa sapidissima (American Shad)

The optimal growth and development temperatures for American shad are similar among life stages—ranging from 10–26°C. Greene et al. (2009, reference not specified) reported a narrower optimal range for adults, between 13–18°C. Minimum DO concentrations for American Shad range between 4–5 mg/L; although, American shad are more likely to be present in habitats with greater than 5.0 mg/L DO (Bilkovic et al. 2002; Feyrer and Healey 2003).

Temperature

Laboratory and Review Studies

Table 13. *Alosa sapidissima* (American Shad) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Eggs/ embryos	Optimum temperature	13–26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Klauda et al. 1991, cited in Roberge et al. 2002
Larva	Optimum temperature	15–25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Stier and Crance 1985, cited in Greene et al. 2009
Larva	Suitable[12] temperature	13–26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Ross et al. 1993, cited in Greene et al. 2009
Larva	Optimum temperature	15.5–26.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Klauda et al. 1991, cited in Roberge et al. 2002

[12] Suitable is defined as right or appropriate for a particular purpose.

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Optimum temperature	10–25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference was not specified in Greene et al. 2009
Juvenile and adult	Optimum temperature	13–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Greene et al. 2009
Spawning	Optimum temperature	14–24.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Ross et al. 1993, in Greene et al. 2009
Eggs/ embryos	Eggs develop within 2 to 15.5 days with increasing temperature	11–27	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Limburg 1996, cited in Greene et al. 2009
Eggs/ embryos	Tolerable[13] temperature	8–30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Greene et al. 2009
Eggs/ embryos	Hatch in 8–12 days	11–15	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Bradbury et al. 1999, cited in Roberge et al. 2002
Larva	No change in density	26–27	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Ross 1993, cited in Greene et al. 2009
Larva	Tolerable temperature	10–30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Greene et al. 2009
Young-of-year	Tolerable temperature	13–26.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Roberge et al. 2002

[13] Tolerable is defined as able to be endured.

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Tolerable temperature	3–35	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference was not specified in Greene et al. 2009
Juvenile	Higher initial growth rates	28.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Limburg 1996, cited in Greene et al. 2009
Juvenile	Increased heat shock protein transcription	34–36	Sample size: 49 Acclimation temperature: 25 Rate of change: 1°C per day Feeding history: Ad libitum 2x per day Control: Yes	Laboratory	Bayse et al. 2020
Juvenile	Mortality	34–36	Sample size: 12 Acclimation temperature: 25 Rate of change: 1°C per day Feeding history: Ad libitum 2x per day Control: Yes	Laboratory	Bayse et al. 2020
Spawning	Tolerable temperature	8–26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Greene et al. 2009
Spawning	Maximum spawning temperature	26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Beasley and Hightower 2000, cited in Roberge et al. 2002

In Situ, Model, or Other Publication Types

Table 14. *Alosa sapidissima* (American Shad) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Eggs/ embryos	Present	13.2–19.5	Sample size: NA	In situ	Bilkovic et al. 2002[14]
Larva	Present	12.3–20.5	Sample size: NA	In situ	Bilkovic et al. 2002[14]
Not specified	Present	18.1–19.3	Sample size: 63 (across all locations)	In situ	Feyrer and Healey 2003[14]

[14] This paper summarized data from multiple locations.

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Maximum individuals caught	8–14	Sample size: NA	In situ	NCEHNR 1990

Dissolved Oxygen

Laboratory and Review Studies

Table 15. *Alosa sapidissima* (American Shad) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Optimal and preferred values					
Eggs/ embryos	Successful incubation and hatching	4 (minimum)	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Klauda et al. 1991, Maurice et al. 1987, and Chittenden 1973a, cited in Greene et al. 2009
Spawning	Optimal nursery area	>5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Bilkovic et al. 2000, cited in Greene et al. 2009
Eggs/ embryos	High mortality, behavioral changes and/or high chronic or acute DO requirements	<3.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Dove and Nyman 1995 and Stier et al. 1985, cited in The Patrick Center for Environmental Research 2018
Eggs/ embryos	Present	10.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Bilkovic 2000, cited in Greene et al. 2009
Larva	Present	9	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Bilkovic et al. 2000, cited in Greene et al. 2009
Juvenile	Present	8.1	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Bilkovic et al. 2000, cited in Greene et al. 2009

Attachment #8: White Sturgeon Literature Review

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Juvenile	High mortality or behavioral changes and/or had relatively high chronic or acute DO requirements	<3.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Dove and Nyman 1995 and Stier et al. 1985, cited in The Patrick Center for Environmental Research 2018.
Adult	High mortality or behavioral changes and/or had relatively high chronic or acute DO requirements	<3.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Dove and Nyman, 1995 and Stier et al. 1985, cited in The Patrick Center for Environmental Research 2018
Spawning	Spawning occurs	4 (minimum)	Sample size: NA Tolerable temperature: 8–26°C Optimal temperature: 14–24.5°C Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Greene et al. 2009

In Situ, Model, or Other Publication Types

Table 16. *Alosa sapidissima* (American Shad) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Eggs/ embryos	Present	7.5–12	Sample Size: NA Temperature: 15 and 16°C	In situ	Bilkovic et al. 2002[14]
Larva	Present (more dispersed than the presence of eggs)	7.5–11.3	Sample Size: NA Temperature: 15–15.9°C	In situ	Bilkovic et al. 2002[14]
Not specified	Present	7.6–8.9	Sample Size: 63 Temperature: 18.1±5.3°C to 19.3±5.1°C	In situ	Feyrer and Healey 2003[14]

Catostomus ardens (Utah Sucker)

No optimal temperature or DO concentration values for Utah sucker were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 17. *Catostomus ardens* (Utah Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present	27	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

No in situ, model, or other types of publications published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Catostomus columbianus (Bridgelip Sucker)

Optimal spawning temperatures for bridgelip sucker range between 6–13°C (multiple sources, cited in Roberge et al. 2002). No DO concentration values for bridgelip sucker were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 18. *Catostomus columbianus* (Bridgelip Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Spawning	Peak spawning	8–13	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Dauble 1980, cited in Roberge et al. 2002
Spawning	Optimal spawning	6–13	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple sources cited in Roberge et al. 2002

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning initiated	6–10	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Dauble 1980, cited in Roberge et al. 2002
Not specified	Absent above this temperature	25.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Huff et al. 2005, cited in Schultz and Bertrand 2011

In Situ, Model, or Other Publication Types

Table 19. *Catostomus columbianus* (Bridgelip Sucker) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Present	11–25	Sample size: NA	In situ	Ebersole 2001
Not specified	Present (average maximum temperature)	20.8	Sample size: 18 (of 48 sites)	Model[11]	Porter et al. 2000
Not specified	Absent (average maximum temperature)	19.4	Sample size: 30 (of 48 sites)	Model[11]	Porter et al. 2000

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Catostomus discobolus (Bluehead Sucker)

Peak spawning for bluehead sucker occurs at 10–12.7°C (Propst et al. 2001). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 20. *Catostomus discobolus* (Bluehead Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present	28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 21. *Catostomus discobolus* (Bluehead Sucker) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Eggs/ embryos	Peak gonadosomatic index	10.1–12.7	Sample size: NA	In situ	Propst et al. 2001
Spawning	Peak spawning	10	Sample size: NA	In situ	Propst et al. 2001
Larva	Present	16	Sample size: NA	In situ	Fraser et al. 2019
Juvenile	Present	12–16	Sample size: NA	In situ	Fraser et al. 2019
Spawning	Spawning observed	6–13	Sample size: NA	In situ	Propst et al. 2001
Spawning	Spawning movement	9.1–14.0	Sample size: 40–63	In situ	Fraser et al. 2017
Not specified	Upper thermal tolerance	25	Sample size: NA	Model	Wyoming Game and Fish Department n.d. cited in Walters et al. 2018
Not specified	Warming tolerance[15]	8.1	Sample size: NA	Model	Wyoming Game and Fish Department n.d. cited in Walters et al. 2018

[15] The difference between current site temperature and a species' upper thermal tolerance.

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 22. *Catostomus discobolus* (Bluehead Sucker) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Juvenile, young-of-year, adult, spawning (inferred)	Present	4.5–10	Sample Size: NA Temperature: NA	In situ	Propst et al. 2001[16]

Catostomus macrocheilas (Largescale Sucker)

No optimal temperature or DO concentration values for largescale sucker were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 23. *Catostomus macrocheilas* (Largescale Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Mortality	29.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Hillman et al. 1999

[16] This paper summarized data for spring and summer sampling seasons.

In Situ, Model, or Other Publication Types

Table 24. *Catostomus macrocheilas* (Largescale Sucker) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present (peak summer temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Present	11–25	Sample size: NA	In situ	Ebersole 2001
Not specified	Present	21.4	Sample size: 14 (of 48 sites)	Model[11]	Porter et al. 2000
Not specified	Absent	19.3	Sample size: 34 (of 48 sites)	Model[11]	Porter et al. 2000

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 25. *Catostomus macrocheilas* (Largescale Sucker) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	64–78% minimum	Sample Size: NA Temperature: 23–25°C	In situ	Waite and Carpenter 2000

Catostomus occidentalis (Sacramento Sucker)

No optimal temperature or DO concentration values for Sacramento sucker were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 26. *Catostomus occidentalis* (Sacramento Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Highest swimming performance among treatment groups	15	Sample size: 7 Acclimation temperatures: 10, 15, 20 Rate of change: 1°C per day Feeding history: Fed commercial trout pellets and frozen adult Artemia; fasted for 48h prior to experiment Control: No	Laboratory	Myrick and Cech 2000

In Situ, Model, or Other Publication Types

Table 27. *Catostomus occidentalis* (Sacramento Sucker) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present	18.1–19.3	Sample size: 278 (across all sample locations)	In situ	Feyrer and Healey 2003[14]
Juvenile and adult (inferred)	Present	17.7–24.5	Sample size: 484	In situ	Harvey et al. 2002

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 28. *Catostomus occidentalis* (Sacramento Sucker) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Not specified	Present	7.6–8.9	Sample Size: 278 Temperature: 18.1±5.3°C to 19.3±5.1°C	In situ	Feyrer and Healey 2003[14]

Catostomus platyrhynchus (Mountain Sucker)

No optimal temperature or DO concentration values for mountain sucker were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 29. *Catostomus platyrhynchus* (Mountain Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Upper thermal tolerance (endpoint was final loss of equilibrium)	32.3–33.6	Sample size: 18 Acclimation temperatures: Three acclimation temperatures ranged 20–25 (±1.5) Rate of change: 0.3°C per minute Feeding history: Supplied with a diet of attached periphyton collected from local waterbodies, supplemented with live and frozen chironomid larvae Control: No	Laboratory	Schultz and Bertrand 2011
Adult	Upper thermal tolerance (endpoint was flaring opercula)	32.5–33.7	Sample size: 18 Acclimation temperatures: Three acclimation temperatures ranged 20–25 (±1.5) Rate of change: 0.3°C per minute Feeding history: Supplied with a diet of attached periphyton collected from local waterbodies, supplemented with live and frozen chironomid larvae Control: No	Laboratory	Schultz and Bertrand 2011
Adult	Upper thermal tolerance (endpoint was initial loss of equilibrium)	31.5–33.4	Sample size: 18 Acclimation temperatures: Three acclimation temperatures ranged 20–25 (±1.5) Rate of change: 0.3°C per minute Feeding history: Supplied with a diet of attached periphyton collected from local waterbodies, supplemented with live and frozen chironomid larvae Control: No	Laboratory	Schultz and Bertrand 2011

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Upper thermal tolerance (endpoint was mortality)	32.9–34.0	Sample size: 18 Acclimation temperatures: Three acclimation temperatures ranged 20–25 (±1.5) Rate of change: 0.3°C per minute Feeding history: Supplied with a diet of attached periphyton collected from local waterbodies, supplemented with live and frozen chironomid larvae Control: No	Laboratory	Schultz and Bertrand 2011
Not specified	Present	15.5–23.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 30. *Catostomus platyrhynchus* (Mountain Sucker) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Upper thermal tolerance	22	Sample size: present at 458 of 1559 sites	Model	Walters et al. 2018
Not specified	Warming tolerance	5.5	Sample size: present at 458 of 1559 sites	Model	Walters et al. 2018

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Catostomus snyderi (Klamath Largescale Sucker)

No optimal temperature or DO concentration values for Klamath largescale sucker were reported by the sources identified in our literature search. A minimum DO concentration of 1 mg/L was reported (Castleberry and Cech 1992; multiple sources, cited in Moyle et al. 2015).

Temperature

Laboratory and Review Studies

Table 31. *Catostomus snyderi* (Klamath Largescale Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult (inferred)	Critical thermal maximum (endpoint was permanent loss of equilibrium)	32.6	Sample size: 1 Acclimation temperature: 20 (6 weeks) Rate of change: 0.3°C per min. Feeding history: Satiated Control: Yes	Laboratory	Castleberry and Cech 1992
Spawning	Reproduction initiated	5.5–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Janney et al. 2007 and Ellsworth et al. 2009, cited in Moyle et al. 2015
Spawning	Spawning migration initiated	>10	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Ellsworth et al. 2009, cited in Moyle et al. 2015
Not specified	Temperature tolerance range	25–32	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Falter and Cech 1991, Scoppetone and Vinyard 1991, Castleberry and Cech 1992, and Moyle 2002, cited in Moyle et al. 2015

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

Laboratory and Review Studies

Table 32. *Catostomus snyderi* (Klamath Largescale Sucker) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Not specified	Minimum DO tolerance	1	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Falter and Cech 1991, Scoppetone and Vinyard 1991, Castleberry and

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		Cech 1993 [*sic*], cited in Moyle et al. 2015
Adult (inferred)	Critical oxygen minima (endpoint was permanent loss of equilibrium)	0.8 (0.5–1.1)	Sample size: 3 Temperature: 20°C Rate of change: 1.25 torr per min Feeding history: ad libitum Control: Yes	Laboratory	Castleberry and Cech 1992

In Situ, Model, or Other Publication Types

No in situ or model studies were found published after 1990 for this coolwater species.

Catostomus warnerensis (Warner Sucker)

No optimal temperature or DO concentration values for warner sucker were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 33. *Catostomus warnerensis* (Warner Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Present	14–20	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	USEPA 1998

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater species.

Chasmistes brevirostris (Shortnose Sucker)

No optimal temperature or DO concentration values for shortnose sucker were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 34. *Chasmistes brevirostris* (Shortnose Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Larva	Upper median lethal concentration range (LC50)[17]	31.82–31.85	Sample size: 40 per test chamber Acclimation temperature: 20 Rate of change: NA Duration of exposure: 24-96 hours Feeding history: During acclimation, larvae were fed 3x daily; during treatments, larvae were fed ad libitum 2x daily were fasted Control: Yes	Laboratory	Saiki et al. 1999
Juvenile	Upper median lethal concentration range (LC50)	30.35–31.07	Sample size: 10 per test chamber Acclimation temperature: 20 Rate of change: NA Duration of exposure: 24-96 hours Feeding history: During acclimation, juveniles 1x daily; during treatments, juveniles were fasted Control: Yes	Laboratory	Saiki et al. 1999
Adult (inferred)	Critical thermal maximum (endpoint was permanent loss of equilibrium)	32.7 (32.1–33.3)	Sample size: 10 Acclimation temperature: 20 (6 weeks) Rate of change: 0.3°C per min. Feeding history: Satiated Control: Yes	Laboratory	Castleberry and Cech 1992
Spawning	Spawning migration initiated	5.5–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in USEPA 1998

[17] LC50 – lethal concentration that will kill 50 percent of the sample population.

In Situ, Model, or Other Publication Types

Table 35. *Chasmistes brevirostris* (Shortnose Sucker) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Present	9.9–28.6	Sample size: NA	In situ	Burdick et al. 2008
Not specified	High stress threshold	28	Sample size: NA	Other (biological opinion)	USFWS 2015
Not specified	Present (tolerable habitat)	<28	Sample size: NA	Other (biological opinion)	USFWS 2015

Dissolved Oxygen

Laboratory and Review Studies

Table 36. *Chasmistes brevirostris* (Shortnose Sucker) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Larva	Acute toxicity, LC50 (endpoint was not specified)	2.4	Sample size: NA Acclimation temperature: 31.2°C Rate of change: NA Feeding history: NA Control: NA	Review	Klamath Tribes 1996 report (USBR April 1997), cited in USEPA 1998
Larva	Lowest LC50 (endpoint is mortality)	1.92 (1.89–1.96)	Sample size: 40 per test chamber Temperature: 20°C Rate of change: NA Duration of exposure: 24 hours Feeding history: larva 3x daily and juveniles 1x daily; larvae fed ad libitum 2x daily and juveniles fasted post trial Control: Yes	Laboratory	Saiki et al. 1999
Larva	Lowest LC50 (endpoint is mortality)	2.04 (1.90–2.18)	Sample size: 40 per test chamber Temperature: 20°C Rate of change: NA Duration of exposure: 48 hours Feeding history: larva 3x daily; larvae	Laboratory	Saiki et al. 1999

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Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			fed ad libitum 2x daily fasted post trial Control: Yes		
Larva	Lowest LC50 (endpoint is mortality)	2.09 (1.90–2.29)	Sample size: 40 per test chamber Temperature: 20°C Rate of change: NA Duration of exposure: 72 and 96 hours Feeding history: larva 3x daily; larvae fed ad libitum 2x daily fasted post trial Control: Yes	Laboratory	Saiki et al. 1999[18]
Juvenile	Acute toxicity, LC50	2.4	Sample size: NA Acclimation temperature: 27.8°C Rate of change: NA Feeding history: NA Control: NA	Review	Klamath Tribes 1996 report (USBR April 1997), cited in USEPA 1998
Juvenile	Mortality (initial)	3–4	Sample size: NA Acclimation temperature: NA Rate of change: NA Duration of exposure: 96 hours Feeding history: NA Control: NA	Review	ODEQ 1995, cited in WSDOE 2002
Juvenile	Lowest LC50 (endpoint is mortality)	1.14 (0.84–1.55)	Sample size: 40 per test chamber Temperature: 20°C Rate of change: NA Duration of exposure: 24 hours Feeding history: larva 3x daily and juveniles 1x daily; larvae fed ad libitum 2x daily and juveniles fasted post trial Control: Yes	Laboratory	Saiki et al. 1999
Juvenile	Lowest LC50 (endpoint is mortality)[18]	1.34 (1.15–1.55)	Sample size: 40 per test chamber Temperature: 20°C Rate of change: NA Duration of exposure: 48, 72, and 96 hours	Laboratory	Saiki et al. 1999

[18]Same effect reported for different exposure durations.

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			Feeding history: larva 3x daily and juveniles 1x daily; larvae fed ad libitum 2x daily and juveniles fasted post trial Control: Yes		
Juvenile	Present	4.5–12.9	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in USEPA 1998
Juvenile and adult	Present	9 (4–13)	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Simon 1998, cited in USPEA 1998
Adult (inferred)	Critical oxygen minima (endpoint was permanent loss of equilibrium)	0.7 (0.45–1)	Sample size: 10 Temperature: 20°C Rate of change: decrease of 1.25 torr per min Feeding history: ad libitum Control: Yes	Laboratory	Castleberry and Cech 1992

In Situ, Model, or Other Publication Types

Table 37. *Chasmistes brevirostris* (Shortnose Sucker) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Not specified	Tolerable limit	>4	Sample Size: NA Temperature: <28°C	Other (biological opinion)	USFWS 2015
Juvenile	Reduced growth	<1	Sample Size: NA Temperature: >22°C	In situ	Terwilliger et al. 2003, cited in Banish et al. 2009
Juvenile	Present	2–12	Sample Size: NA Temperature: 9.9–28.6°C; low stress threshold is 25°C	In situ	Burdick et al. 2008
Juvenile	Reduced growth (endpoint was otolith daily increment widths)	<1	Sample Size: 567 Temperature: >22°C	Model	Terwilliger et al. 2003
Adult	Present	8.3–11.6	Sample Size: 121 Temperature: 14.7°C	In situ	Banish et al. 2009[14]

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			(Pelican Bay) and 19.5°C (Mid-north)		

Cottus asper (Prickly Sculpin)

No optimal temperature or DO concentration values for prickly sculpin were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 38. *Cottus asper* (Prickly Sculpin) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present	25–28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Moyle et al. 2015

In Situ, Model, or Other Publication Types

Table 39. *Cottus asper* (Prickly Sculpin) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present	4.29–20.37	Sample size: NA	In situ	Mueller et al. 2002
Not specified	Absent (average maximum summer temperature)	19.2	Sample size: 32 (of 48 sites)	Model[11]	Porter et al. 2000
Not specified	Present (average maximum summer temperature)	21.3	Sample size: 16 (of 48 sites)	Model[11]	Porter et al. 2000

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 40. *Cottus asper* (Prickly Sculpin) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L or % air saturation)	Study design considerations	Study type	Reference
Juvenile, young-of-year, adult, spawning (inferred)	Present	7.3–9.4	Sample Size: NA Temperature: 11.9°C (surface) and 4.3°C (depth)	In situ	Mueller et al. 2002
Juvenile, young-of-year, adult, spawning (inferred)	Present	6.1–7.7	Sample Size: NA Temperature: 20.4°C (surface) and 4.6°C (depth)	In situ	Mueller et al. 2002
Juvenile, young-of-year, adult, spawning (inferred)	Present	3.7–4.9	Sample Size: NA Temperature: 9.9°C (surface) and 5°C (depth)	In situ	Mueller et al. 2002
Not specified	Present	64%	Sample Size: NA Temperature: 23°C	In situ	Waite et al. 2000

Cottus bairdii (Mottled Sculpin)

The final temperature preferendum[19] of mottled sculpin is between 12.8–18.3°C (multiple references, cited in Hillman et al. 1999). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

[19] Preferendum is the range of a gradient item, such as temperature, that seems to be positively attractive to a motile organism when a selection is available.

Table 41. ***Cottus bairdii*** **(Mottled Sculpin) Temperature Data from Laboratory and Review Studies**

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Not specified	Final temperature preferendum	12.8–18.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Present	2–23	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Steinmetz et al. 2002, cited in Willink 2017
Not specified	Present (observed range)	<24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 42. ***Cottus bairdii*** **(Mottled Sculpin) Temperature Data from In Situ, Model, or Other Publication Types**

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning activities observed	4–16	Sample size: 172	In situ	DeHaven et al. 1992
Not specified	Present (maximum weekly average tolerance)	24.3	Sample size: NA	Model	Eaton and Scheller 1996
Not specified	Present	14.44	Sample size: 273	In situ	Amrhein 2004
Not specified	Present	7.78–15.56	Sample size: NA	In situ	Wynn 1999
Not specified	Present	15.9–24.6	Sample size: NA	In situ	Hinz et al. 2011
Not specified	Present	2–19	Sample size: NA	In situ	Thompson et al. 2001
Not specified	Present	17.83	Sample size: NA	Model	Zorn et al. 2009

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 43. *Cottus bairdii* (Mottled Sculpin) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L or % air saturation)	Study design considerations	Study type	Reference
Not specified	Present	8	Sample Size: NA Temperature: NA	In situ	NCDENR 2005
Not specified	Present	68–79%	Sample Size: NA Temperature: 17–18 °C	In situ	Waite and Carpenter 2000

Cottus gulosus (Riffle Sculpin)

No optimal temperature or DO concentration values for riffle sculpin were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 44. *Cottus gulosus* (Riffle Sculpin) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Mortality	>30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Moyle et al. 2015
Not specified	Present (most abundant)	<26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Moyle et al. 2015

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater species.

Cottus klamathensis (Marbled Sculpin)

The marbled sculpin has a preferred temperature range of 10–15°C (Markle et al. 1996, cited in Moyle et al. 2015). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 45. *Cottus klamathensis* (Marbled Sculpin) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Not specified	Present (preferred temperature range)	10–15	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Markle et al. 1996, cited in Moyle et al. 2015
Not specified	Mortality	>25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Moyle et al. 2015

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Cottus perplexus (Reticulate Sculpin)

No optimal temperature or DO concentration values for reticulate sculpin were reported by the sources identified in our literature search.

Temperature

No temperature data published in 1990 or later were found for this species.

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 46. *Cottus perplexus* (Reticulate Sculpin) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	78%	Sample Size: NA Temperature: 25°C	In situ	Waite and Carpenter 2000
Not specified	Present	64%	Sample Size: NA Temperature: 23°C	In situ	Waite and Carpenter 2000
Not specified	Present	68–79%	Sample Size: NA Temperature: 17–18°C	In situ	Waite and Carpenter 2000

Deltistes luxatus (Lost River Sucker)

No optimal temperature or DO concentration values for Lost River sculpin were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 47. *Deltistes luxatus* (Lost River Sucker) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Larva	LC50 values	31.69–31.93	Sample size: 40 per test chamber, 6 test chambers Acclimation temperature: 20 Rate of change: NA Duration of exposure: 24-96 hours Feeding history: During acclimation, larvae were fed 3x daily; during treatments, larvae were fed ad libitum 2x daily Control: Yes	Laboratory	Saiki et al. 1999
Larva	LC50 values	30.51–30.76	Sample size: 10 per test chamber Acclimation temperature: 20 Rate of change: NA Duration of exposure: 24-96 hours	Laboratory	Saiki et al. 1999

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: During acclimation, larvae were fed 3x daily; during treatments, larvae were fed ad libitum 2x daily Control: Yes		
Spawning	Spawning migration initiated	5.5–19	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in USEPA 1998

In Situ, Model, or Other Publication Types

Table 48. *Deltistes luxatus* (Lost River Sucker) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Present (near-shore habitat use)	9.9–28.6	Sample size: NA	In situ	Burdick et al. 2008
Not specified	High stress threshold	28	Sample size: NA	Other (biological opinion)	Loftus et al. 2001, cited in USFWS 2015
Not specified	Present (tolerable habitat)	<28	Sample size: NA	Other (biological opinion)	USFWS 2015

Dissolved Oxygen

Laboratory and Review Studies

Table 49. *Deltistes luxatus* (Lost River Sucker) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Larva	Acute toxicity, LC50	2.0	Sample size: NA Acclimation temperature: 30.5°C Rate of change: NA Feeding history: NA Control: NA	Review	Klamath Tribes 1996 report (USBR April 1997), cited in USEPA 1998
Larva	Lowest LC50 (endpoint is mortality)	2.01 (1.90–2.13)	Sample size: 40 per test chamber Temperature: 20°C Rate of change: NA Duration of exposure: 24 hours	Laboratory	Saiki et al. 1999

Attachment #8: White Sturgeon Literature Review

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			Feeding history: larva 3x daily; post trial, larvae fed ad libitum 2x daily Control: Yes		
Larva	Lowest LC50 (endpoint is mortality)	2.10 (2.07–2.13)	Sample size: 40 per test chamber Temperature: 20°C Rate of change: NA Duration of exposure: 48, 72, and 96 hours Feeding history: larva 3x daily; post trials, larvae fed ad libitum 2x daily Control: Yes	Laboratory	Saiki et al. 1999[18]
Juvenile	Acute toxicity, LC50	2	Sample size: NA Acclimation temperature: 29.9°C Rate of change: NA Feeding history: NA Control: NA	Review	Klamath Tribes 1996 report (USBR April 1997), cited in USEPA 1998
Juvenile	Present	4.5–12.9	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in USEPA 1998
Juvenile	Mortality	3–4	Sample size: NA Acclimation temperature: NA Rate of change: NA Duration of exposure: 96 hours Feeding history: NA Control: NA	Review	ODEQ 1995, cited in WSDOE 2002
Juvenile	Lowest LC50 (endpoint is mortality)	1.58 (1.35–1.86)	Sample size: 10 per test chamber Temperature: 20°C Rate of change: NA Duration of exposure: 24 and 48 hours Feeding history: fasted post trial Control: Yes	Laboratory	Saiki et al. 1999[18]
Juvenile	Lowest LC50 (endpoint is mortality)	1.62 (1.41–1.86)	Sample size: 10 per test chamber Temperature: 20°C Rate of change: NA	Laboratory	Saiki et al. 1999[18]

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			Duration of exposure: 72 and 96 hours Feeding history: juveniles 1x daily; fasted post trial Control: Yes		
Juvenile and adult	Acute toxicity, LC50	2.8	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Klamath Tribes 1996 report (USBR April 1997), cited in USEPA 1998
Juvenile and adult	Present	9 (4–13)	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Simon 1998, cited in USEPA 1998
Juvenile and adult	Present	6	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in USEPA 1998

In Situ, Model, or Other Publication Types

Table 50. *Deltistes luxatus* (Lost River Sucker) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Not specified	Tolerable limit	>4	Sample Size: NA Temperature: <28°C	Other (biological opinion)	USFWS 2015
Juvenile	Present	2–12	Sample Size: NA Temperature: 9.9–28.6°C; low stress threshold is 25°C	In situ	Burdick et al. 2008
Juvenile	Reduced growth (endpoint is otolith daily increment widths)	<4	Sample Size: 385 Temperature: >22°C	Model	Terwilliger et al. 2003
Juvenile and adult	Absent (only 3-13% of observations)	<4	Sample Size: 91 Temperature: 14.7°C (Pelican Bay) and 19.5°C (Mid-north)	In situ	Banish et al. 2009

Esox americanus (Grass Pickerel)

No optimal temperature or DO concentration values for grass pickerel were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 51. *Esox americanus* (Grass Pickerel) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Present	10	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Pennsylvania Fish and Boat Commission 2007

In Situ, Model, or Other Publication Types

Table 52. *Esox americanus* (Grass Pickerel) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present	13.7–27.5	Sample size: NA	In situ	Hinz et al. 2011
Not specified	Present	21.22	Sample size: NA	Model	Zorn et al. 2009

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Esox lucius (Northern Pike)

The optimal temperature range for northern pike varied by life stage but generally fell within the range of 19–26°C. The optimal temperature appears to increase through development from eggs (8–14°C) to larva (12–21°C) (multiple references, cited in Souchon and Tissot 2012) to juveniles and adults (19–26°C). A model by Missaghi et al. (2017) found northern pike to exhibit quality growth at DO concentrations greater than 3 mg/L.

Temperature

Laboratory and Review Studies

Table 53. *Esox lucius* (Northern Pike) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Eggs/ embryos	Present (optimal temperature range)	8–14	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Souchon and Tissot 2012
Larva	Present (optimal temperature range)	12–21	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Souchon and Tissot 2012
Juvenile	Optimal temperature	22–23	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Casselman 1978; Casselman and Lewis 1996, cited in Roberge et al. 2002
Juvenile	Final temperature preferendum	24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999.
Juvenile	Optimum growth temperature	21–26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Optimum growth temperature	26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Ford et al. 1995
Juvenile and adult	Optimal temperature	19–21	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Casselman 1978 and Casselman and Lewis 1996, cited in Roberge et al. 2002
Adult	Laboratory preferred temperature	19–24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Multiple references, cited in Lyons et al. 2009
Adult	Optimal temperature range	10–24	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Multiple references cited in Souchon and Tissot 2012

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Adult	Optimum temperature for growth	19–21	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference was not specified in Ford et al. 1995
Adult	Optimum growth temperature	19–21	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Final temperature preferendum	23–24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Optimum temperature range	9–25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Optimum growth temperature	19–26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Eggs/ embryos	Average % of hatching embryos was 79.2	28–32	Sample size: 350 per batch Acclimation temperature: 12 Rate of change: NA Duration of exposure: 5, 15, 25 mins (5, 15 and 25 mins after fertilization) Feeding history: NA Control: Yes	Laboratory	Lucynski and Woznicki 1995
Eggs/ embryos	Average % of hatching embryos was 34.2	27–29	Sample size: 350 per batch Acclimation temperature: 12 Rate of change: NA Duration of exposure: 5, 10, 20 mins (5, 10, and 15 mins after fertilization) Feeding history: NA Control: Yes	Laboratory	Lucynski and Woznicki 1995
Eggs/ embryos	Survival to hatch was 12.7–92.8%	27	Sample size: 350 per batch Acclimation temperature: 12 Rate of change: Instant heat shock Duration of exposure: 5–20 mins (5–15 mins after	Laboratory	Lucynski and Woznicki 1995

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			fertilization) Feeding history: NA Control: Yes		
Eggs/ embryos	Survival to hatch was 1.9–107.9%[20]	28	Sample size: 350 per batch Acclimation temperature: 12 Rate of change: Instant heat shock Duration of exposure: 5–25 mins (5–25 mins after fertilization) Feeding history: NA Control: Yes	Laboratory	Lucynski and Woznicki 1995
Eggs/ embryos	Survival to hatch was 0.8–91.3%	29	Sample size: 350 per batch Acclimation temperature: 12 Rate of change: Instant heat shock Duration of exposure: 5–20 mins (5–15 mins after fertilization) Feeding history: NA Control: Yes	Laboratory	Lucynski and Woznicki 1995
Eggs/ embryos	Survival to hatch was 0.6–54.6%	30	Sample size: 350 per batch Acclimation temperature: 12 Rate of change: Instant heat shock Duration of exposure: 5–25 mins (5–25 mins after fertilization) Feeding history: NA Control: Yes	Laboratory	Lucynski and Woznicki 1995
Eggs/ embryos	Survival to hatch was 0–57.7%	32	Sample size: 350 per batch Acclimation temperature: 12 Rate of change: Instant heat shock Duration of exposure: 5–25 mins (5–25 mins after fertilization) Feeding history: NA Control: Yes	Laboratory	Lucynski and Woznicki 1995
Eggs/ embryos	Upper limit of resistance range	23	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Souchon and Tissot 2012
Larva	Upper limit of resistance range	28	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Multiple references cited in Souchon and Tissot 2012

[20] The authors of this paper did not explain how survival to hatch was calculated or how the value could be >100%.

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Juvenile	Present	19–21	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Casselman and Lewis 1996, cited in Roberge et al. 2002
Juvenile	Present	5.8–33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Zero net growth	28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Upper incipient lethal temperature	33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999.
Juvenile	Maximum weekly average temperature	28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Short-term maximum[21]	30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Present	1–29.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999.
Adult	Critical thermal maxima	30.8–33.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Multiple references, cited in Lyons et al. 2009

[21] The maximum temperature, based on experimental data, that 50% of the fish could survive for a short time (1,000 minutes to 7 days).

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Upper limit of resistance range	31	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references cited in Souchon and Tissot 2012
Adult	Upper incipient lethal temperature	29.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Maximum weekly average temperature	28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Short-term maximum	30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Spawning	Spawning initiated	4.4–12	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	McPhail and Lindsey 1970, Scott and Crossman 1973, and Casselman and Lewis 1996, cited in Roberge et al. 2002
Spawning	Present	4.44–10	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Pennsylvania Fish and Boat Commission 2007
Spawning	Present	7.78–12.22	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Diana 1995, cited in Smith et al. 2016
Spawning	Present	1.67–7.22	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Brautigam and Lucas 2008
Not specified	Maximum average temperature tolerance	27.78	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Casselman 1978 and Craig 2008, cited in Smith et al. 2016
Not specified	Limited growth and size	>21	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Margenau et al. 1998, cited in Smith et al. 2016

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Not specified	Upper lethal temperature	28.4–34	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper critical range	30–34	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 54. *Esox lucius* (Northern Pike) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Adult	Suitable habitat	<26	Sample size: 17	In situ	Headrick and Carline 1993
Not specified	Lower to upper good-growth temperature	13.2–28.2	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Model	Stefan et al. 1993, cited in Fang et al. 2004
Not specified	Preferred temperature range in August in Minnesota	16–21	Sample size: 4-18 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	In situ	Pierce et al. 2013
Juvenile	Present	6–13	Sample size: 4-25	In situ	Rich 1992[14]
Juvenile and adult	Present (positively associated with decreasing temperature)	16.8–31	Sample size: 7	In situ	Bhagat and Ruetz 2011
Adult	Present	10–25	Sample size: NA	In situ	Rich 1992
Adult	Present	2.22–8.89	Sample size: 935	In situ	Donabauer et al. 2012
Adult	Upper temperature tolerance limit	28.4	Sample size: 198	Model	Stefan et al. 1994

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Adverse fish growth (maximum 95% weekly temperature)	27.5–28.0	Sample size: 198	Model	Stefan et al. 1994
Adult	Adverse fish growth (maximum 99% weekly temperature)	28.1–28.6	Sample size: 198	Model	Stefan et al. 1994
Not specified	Maximum weekly average tolerance	28	Sample size: NA	Model	Eaton and Scheller 1996
Not specified	Estimated 95th percentile weekly mean temperature (based on FTDMS[22] database)	28	Sample size: 72	In situ	Eaton et al. 1995a
Not specified	Upper habitat temperature limit	31.1	Sample size: NA	Model	Eaton et al. 1995 and Stefan et al. 1993, cited in Fang et al. 2004
Not specified	Lethal temperature	>30.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Model	Stefan et al. 2001, cited in Missaghi et al. 2017
Not specified	Present	16.2–26.8	Sample size: NA	In situ	Hinz et al. 2011
Not specified	Present	18.95–22.79	Sample size: 4 to 18	In situ	Pierce et al. 2013
Not specified	Absent	>22	Sample size: 57 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	In situ	Pierce et al. 2013
Not specified	Present	21.83	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Model	Zorn et al. 2009

[22] FTDMS – the Fish and Temperature Database Matching System (Eaton et al. 1995).

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Restricted growth criteria	28.2–30.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Model	Stefan et al. 2001, cited in Missaghi et al. 2017

Dissolved Oxygen

Laboratory and Review Studies

Table 55. *Esox lucius* (Northern Pike) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Larva	Survival (99–100%)	9.7 (2.8–10)	Sample size: NA Acclimation temperature: 9±0.3°C Experiment temperature: 15.5±0.2°C Rate of change: moved between containers with different DO levels Feeding history: brackish zooplankton (16±3 prey/mL) 3x daily Control: No	Laboratory	Engström-Öst and Isaksson 2006[23]
Not specified	Present	≥9.4	Sample size: NA Acclimation temperature: <16.11°C Rate of change: NA Feeding history: NA Control: NA	Review	Koza 1998, cited in Donabauer 2011.
Not specified	Present	≥3	Sample size: NA Acclimation temperature: 25°C Rate of change: NA Feeding history: NA Control: NA	Review	Headrick and Carline 1993, cited in Smith et al. 2016

[23] This paper summarized data for multiple exposure treatments.

In Situ, Model, or Other Publication Types

Table 56. *Esox lucius* (Northern Pike) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Optimal and preferred values					
Not specified	DO level needed for good growth	>3	Sample Size: NA Temperature: 16.3–28.2°C	Model	Missaghi et al. 2017
Adult	Absent	<3	Sample Size: 17 Temperature: NA	In situ	Headrick and Carline 1993
Not specified	Present	>3	Sample Size: NA Temperature: <21°C	In situ	Pierce et al. 2013
Not specified	Present	5.65–10.09	Sample Size: 6 Temperature: NA	In situ	Weinke and Biddanda 2018
Not specified	Absent	<3	Sample Size: 57 Temperature: NA	In situ	Pierce et al. 2013
Not specified	Lethal concentration	<3	Sample Size: NA Temperature: NA	Model	Missaghi et al. 2017

Gasterosteus aculeatus (Threespine Stickleback)

Optimal growth temperatures were only reported for juvenile threespine stickleback and all sources reported values between 21.7–23°C. These values are likely upper optima as Hovel et al. (2015) reported low activity and no food consumption at 25°C. Glippa et al. (2017) reported increased larval survival at 8 mg/L DO.

Temperature

Laboratory and Review Studies

Table 57. *Gasterosteus aculeatus* (Threespine Stickleback) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Juvenile	Optimal temperature for growth	22	Sample size: NA Acclimation temperature: 15.5°C Rate of change: 1°C per day Feeding history: Ad libitum feeding Control: No	Laboratory	Hovel et al. 2015
Juvenile	Optimal temperature for growth	21.7	Sample size: NA Acclimation temperature: 15.5°C Rate of change: 1°C per day Feeding history: Ad libitum	Laboratory	Hovel et al. 2015

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			feeding Control: No		
Juvenile	Optimal consumption temperature	23	Sample size: 4 Acclimation temperature: 15.5°C Rate of change: 1°C per day Feeding history: Ad libitum feeding Control: No	Laboratory	Hovel et al. 2015
Not specified	Optimal growth and presence range	21.7 (3.6–30.7)	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: Frozen chironomids twice daily Control: Yes	Laboratory	Lefébure et al. 2011, cited in Glippa et al. 2017
Juvenile	Burst swimming: 15.1-22.8 BL/s (body length/second)	8–22	Sample size: 10 Acclimation temperature: 8–23°C Rate of change: Static Feeding history: Ad libitum blood worms Control: Yes	Laboratory	Guderley et al. 2001
Juvenile	Decreased weight at increased temperature within this range	16–21	Sample size: 25 Acclimation temperature: NA Rate of change: 0.8°C Duration of exposure: 90 days Feeding history: Ad libitum frozen chironomid larvae Control: Yes	Laboratory	Hani et al. 2018
Juvenile	Upper tolerance limit for long-term growth	16–21	Sample size: 25 Acclimation temperature: NA Rate of change: 0.8°C Feeding history: Ad libitum frozen chironomid larvae Control: Yes	Laboratory	Hani et al. 2018
Juvenile	Upper temperature limit for growth	29	Sample size: 10 Acclimation temperature: 21°C Rate of change: 1°C Feeding history: 1x daily ad libitum Control: No	Laboratory	Lefébure et al. 2011
Juvenile	Upper thermal limit for growth	29	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Hovel et al. 2015
Juvenile	Upper thermal limit for growth	21.6–28.8	Sample size: NA Acclimation temperature: NA Rate of change: NA	Laboratory	Hovel et al. 2015

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Juvenile	Upper thermal limit for growth	26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Hovel et al. 2015
Juvenile	Low activity/ no food consumption	25	Sample size: NA Acclimation temperature: 15.5°C Rate of change: 1°C per day Feeding history: Ad libitum feeding Control: No	Laboratory	Hovel et al. 2015
Juvenile and adult	Fish were on average smaller and lighter at 21°C than at 17°C.	17–21	Sample size: 619 Acclimation temperature: 17–21°C Rate of change: Static Feeding history: Ad libitum Control: Yes	Laboratory	Schade et al. 2014
Juvenile and adult	Higher axial muscle activities of citrate synthase and phospho-fructokinase after acclimation at 8°C compared to acclimation at 23°C; daily food intake was twofold higher in warm- than cold-acclimated	20	Sample size: 10 Acclimation temperature: 8 and 23°C Rate of change: Gradual thermal equilibration (~6 h) Feeding history: Ad libitum Control: Yes	Laboratory	Guderley et al. 2001
Juvenile and adult	Mortality rate increased (8.8%–35.2%)	17–21	Sample size: 619 Acclimation temperature: 21°C Rate of change: Static Feeding history: Ad libitum Control: Yes	Laboratory	Schade et al. 2014
Adult	Faster startle speed in Spring compared to warm-acclimated fish	22	Sample size: 10 Acclimation temperature: 8°C Rate of change: Static Feeding history: Ad libitum Control: Yes	Laboratory	Guderley et al. 2001

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Faster startle speed in Fall compared to cold-acclimated fish	22	Sample size: 10 Acclimation temperature: 23°C Rate of change: Static Feeding history: Ad libitum Control: Yes	Laboratory	Guderley et al. 2001
Adult	Mortality of reproductive fish	>33	Sample size: 10–14 fish per pond Acclimation temperature: NA Rate of change: NA Feeding history: Ad libitum Control: Yes	Laboratory	Offill and Walton 1999
Not specified	Stress response in all three heat shock proteins (hsp60, hsp90 and hsp70) and down-regulation of metabolic genes	18–26	Sample size: 188 Acclimation temperature: 16°C Rate of change: 1.5°C per hour Feeding history: Ad libitum Control: Yes	Laboratory	Dammark et al. 2018
Not specified	Critical thermal maximum (endpoint was loss of equilibrium)	31.5–32.0	Sample size: 18 Acclimation temperature: 16°C Rate of change: 1.5°C per hour Feeding history: Ad libitum Control: Yes	Laboratory	Dammark et al. 2018[23]
Not specified	Present (93% capture frequency)	3–15	Sample size: 10 Acclimation temperature: 3 to 15°C Rate of change: Static Feeding history: Fed daily; fasted 24h prior to experiments Control: Yes	Laboratory	Elliott and Leggett 1996
Not specified	Predation rate (1–13 larvae/min)	3–15	Sample size: 10 Acclimation temperature: 3-15°C Rate of change: Static Duration of exposure: 3-30 mins (after 75 larvae ingested) Feeding history: Fed daily; fasted 24h prior to experiments Control: Yes	Laboratory	Elliott and Leggett 1996

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Predation rate (34–40 larvae/hour)	3–15	Sample size: 10 Acclimation temperature: 3-15°C Rate of change: Static Duration of exposure: 6 hours Feeding history: Fed daily; fasted 24h prior to experiments Control: Yes	Laboratory	Elliott and Leggett 1996
Not specified	Thermal maximum	23–24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Malcom 1992, cited in Moyle et al. 1995

In Situ, Model, or Other Publication Types

Table 58. *Gasterosteus aculeatus* (Threespine Stickleback) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Upper bound limit for growth	30.67	Sample size: 115 Acclimation temperature: 15°C Rate of change: 1°C Feeding history: 1x daily ad libitum Control: No	Model	Lefébure et al. 2011
Not specified	Present (peak summer water temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002

Dissolved Oxygen

Laboratory and Review Studies

Table 59. ***Gasterosteus aculeatus*** **(Threespine Stickleback) Dissolved Oxygen Data from Laboratory and Review Studies**

Life stage	DO consideration (effect)	DO value (mg/L or % air saturation)	Study design considerations	Study type	Reference
Optimal and preferred values					
Larva	Increased larvae survival	8.1	Sample size: 18 Temperature: 18.6±0.02°C Rate of change: NA Feeding history: frozen chironomids and occasional mysid shrimp 2x daily Control: Yes	Laboratory	Glippa et al. 2017
Eggs/ embryos	Developmental delays, increased mortalities, lower hatching success	24.7%	Sample size: 20 Temperature: 19±1°C Rate of change: NA Feeding history: ad libitum Control: Yes	Laboratory	Fitzgerald et al. 2017
Eggs/ embryos	Premature hatching	75%	Sample size: 20 Temperature: 19±1°C Rate of change: NA Feeding history: ad libitum Control: Yes	Laboratory	Fitzgerald et al. 2017
Eggs/ embryos	Reduced embryo survival (compared to those exposed to 8.7–9.7 mg/L DO)	2.9–3.9	Sample size: NA Temperature: 16–18°C Rate of change: NA Feeding history: NA Control: Yes	Laboratory	Fox et al. 2018
Juvenile and adult	Absent	<1.6	Sample size: 24 Temperature: 4°C above ambient Rate of change: NA Feeding history: NA Control: No	Laboratory	Moran et al. 2010
Adult	Low DO levels did not have direct effects on mortality	0–13	Sample size: 10–14 fish per pod Temperature: 20.6–36.7°C Rate of change: NA Feeding history: NA Control: Yes	Laboratory	Offill and Walton 1999
Not specified	Tolerant of low DO levels	<3.5	Sample size: NA Acclimation	Review	USEPA 2012, cited in The Patrick

Life stage	DO consideration (effect)	DO value (mg/L or % air saturation)	Study design considerations	Study type	Reference
			temperature: NA Rate of change: NA Feeding history: NA Control: NA		Center for Environmental Research 2018.
Adult	Parental care of nests by males observed	8.7–9.7	Sample size: NA Temperature: 16–18 °C Rate of change: NA Feeding history: NA Control: Yes	Laboratory	Fox et al. 2018

In Situ, Model, or Other Publication Types

Table 60. *Gasterosteus aculeatus* (Threespine Stickleback) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	64%	Sample Size: NA Temperature: 23°C	In situ	Waite and Carpenter 2000

Gila atraria (Utah Chub)

No optimal temperature or DO concentration values for Utah chub were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 61. *Gila atraria* (Utah Chub) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present	15.6–31.1	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999.

In Situ, Model, or Other Publication Types

Table 62. *Gila atraria* (Utah Chub) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Upper thermal tolerance	26	Sample size: present at 458 of the 1559 sites sampled	Model	Reference not specified in Walters et al. 2018
Not specified	Warming tolerance	8.4	Sample size: present at 458 of the 1559 sites sampled	Model	Reference not specified in Walters et al. 2018

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Gila bicolor (Tui Chub)

No optimal temperature or DO concentration values for tui chub were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 63. *Gila bicolor* (Tui Chub) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Preferred thermal maximum (endpoint was not specified)	32.2	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	USEPA 1998
Adult (inferred)	Critical thermal maxima (endpoint was permanent loss of equilibrium)	32.3–34.1	Sample size: 10 Acclimation temperature: 20°C Rate of change: 0.3°C per min. Feeding history: Satiated Control: NA	Laboratory	Castleberry and Cech 1992

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

Laboratory and Review Studies

Table 64. *Gila bicolor* (Tui Chub) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Adult (inferred)	Critical oxygen minima (endpoint was permanent loss of equilibrium)	0.59 (0.4–0.85)	Sample size: 10 Temperature: 20°C Rate of change: 1.25 torr per min Feeding history: ad libitum Control: Yes	Laboratory	Castleberry and Cech 1992

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Gila coerulea (Blue Chub)

No optimal temperature or DO concentration values for blue chub were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 65. *Gila coerulea* (Blue Chub) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult (inferred)	Critical thermal maxima (endpoint was permanent loss of equilibrium)	31.5 (28.3–32.8)	Sample size: 10 Acclimation temperature: 20°C Rate of change: 0.3°C per min. Feeding history: Satiated Control: NA	Laboratory	Castleberry and Cech 1992

In Situ, Model, or Other Publication Types

Table 66. *Gila coerulea* (Blue Chub) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Present	9.9–28.6	Sample size: captured in 79–92% of all net sets in each year	In situ	Burdick et al. 2008

Dissolved Oxygen

Laboratory and Review Studies

Table 67. ***Gila coerulea*** **(Blue Chub) Dissolved Oxygen Data from Laboratory and Review Studies**

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Adult (inferred)	Critical oxygen minima (endpoint was permanent loss of equilibrium)	1.1 (0.6–1.5)	Sample size: 10 Temperature: 20°C Rate of change: 1.25 torr per min Feeding history: ad libitum Control: Yes	Laboratory	Castleberry and Cech 1992

In Situ, Model, or Other Publication Types

Table 68. ***Gila coerulea*** **(Blue Chub) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types**

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Juvenile	Present	2–12	Sample Size: NA Temperature: 9.9–28.6°C; low stress threshold is 25°C	In situ	Burdick et al. 2008

Gila copei (Leatherside Chub)

The optimum growth temperature for juvenile leatherside chub is approximately 23°C (Billman et al. 2008). Although, a model produced by an unspecified reference in Walters et al. (2018, reference not specified) indicated an upper thermal tolerance of 24°C. No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 69. ***Gila copei*** **(Leatherside Chub) Temperature Data from Laboratory and Review Studies**

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Juvenile	Optimal temperature for growth	23–23.2	Sample size: 20 and 25 Acclimation temperature: 12.8, 15.5, 17.9, 19.9, and 22.2°C Rate of change: NA Feeding history: Fed 3x daily during work week, 2x a day on weekends, and fasted 24h prior	Laboratory	Billman et al. 2008

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			to trials Control: Yes		
Juvenile	Upper incipient lethal temperatures (endpoint was mortality)	30.2–30.3	Sample size: 12–150 Acclimation temperature: 16.6, 19.7, 22.6, 25.3, and 28.3°C Rate of change: NA Feeding history: Fed 3x daily during work week, 2x a day on weekends, and fasted 24h prior to trials Control: Yes	Laboratory	Billman et al. 2008
Juvenile	Critical thermal maximum (endpoint was loss of equilibrium)	29.6–35	Sample size: 50 Acclimation temperature: 12.8, 15.5, 17.9, 19.9, and 22.2°C Rate of change: NA Feeding history: Fed 3x daily during work week, 2x a day on weekends, and fasted 24h prior to trials Control: Yes	Laboratory	Billman et al. 2008
Not specified	Present	10–20	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 70. *Gila copei* (Leatherside Chub) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Upper thermal tolerance	23.8	Sample size: present at 458 of the 1559 sites sampled	Model	Reference not specified, cited in Walters et al. 2018
Not specified	Warming tolerance	7.7	Sample size: present at 458 of the 1559 sites sampled	Model	Reference not specified, cited in Walters et al. 2018

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Lampetra lethophaga (Pit-Klamath Brook Lamprey)

The preferred summer habitat temperature of Pit-Klamath brook lamprey was reported as <25°C but the life stage was not specified (Close et al. 2010, cited in Moyle et al. 2015). The preferred temperature of larvae is likely to be substantially lower than 25°C because Meeuwig et al. (2002) reported increased abnormalities and decreased survival at 22°C. No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 71. *Lampetra lethophaga* (Pit-Klamath Brook Lamprey) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Not specified	Preferred habitat temperature during Summer	<25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Close et al. 2010, cited in Moyle et al. 2015
Larva	Increased abnormalities and decreased survival compared to other rearing acclimation groups	22	Sample size: 100 Acclimation temperature: 10, 14, 18, and 22°C Rate of change: adjusted to treatment temperature within 30 min. Feeding history: NA Control: No	Laboratory	Meeuwig et al. 2002

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Lampetra richardsoni (Western Brook Lamprey)

No optimal temperature or DO concentration values for western brook lamprey were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 72. *Lampetra richardsoni* (Western Brook Lamprey) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Larva	Greater percentage of abnormalities and decreased survival compared to other rearing acclimation groups	22	Sample size: 100 Acclimation temperature: 10, 14, 18, and 22°C Rate of change: adjusted to treatment temperature within 30 min. Feeding history: NA Control: No	Laboratory	Meeuwig et al. 2002

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 73. *Lampetra richardsoni* (Western Brook Lamprey) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	>64–78%	Sample Size: NA Temperature: 23–25°C	In situ	Waite and Carpenter 2000[14]

Lampetra tridentate (Pacific Lamprey)

The optimal temperature for survival of embryonic and larval Pacific lamprey ranges from 10–18°C (Meeuwig et al. 2005) and the optimal growth temperature is 21°C (Holmes and Lin 1994, cited in Close 2001). However, Moyle et al. (2015, reference not specified) reported a significant increase in abnormalities in juveniles and adults at temperatures greater than 22°C. No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 74. *Lampetra tridentate* (Pacific Lamprey) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Embryos and larva	Optimal temperature for survival	10–18	Sample size: NA Acclimation temperature: 10–22°C Rate of change: NA Feeding history: NA Control: NA	Laboratory	Meeuwig et al. 2005,
Larva	Optimum temperature for growth	21	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Holmes and Lin 1994, cited in Close 2001
Eggs/ embryos	Hatching observed (after 11 days)	18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Yamazaki et al. 2003, cited in Luzier et al. 2011
Eggs/ embryos	Hatching observed (fertilization was around 26 days at 10°C and 8 days at 22°C)	10–22	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Close et al. 2003, Meeuwig et al. 2005, and Luzier et al. 2007, cited in Moyle et al. 2015
Eggs/ embryos	Increased survival	10–18	Sample size: NA Acclimation temperature: 10–22°C Rate of change: NA Feeding history: NA Control: NA	Laboratory	Meeuwig et al. 2005
Eggs/ embryos	Predation by speckled dace observed	>14	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Brumo 2006, cited in Luzier et al. 2011
Eggs/ embryos and larva	Decreased survival and increased in abnormalities	22	Sample size: NA Acclimation temperature: 10–22°C Rate of change: NA Feeding history: NA Control: NA	Laboratory	Meeuwig et al. 2005

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Larva	Zero development observed	4.85	Sample size: NA Acclimation temperature: 10–22°C Rate of change: NA Feeding history: NA Control: NA	Laboratory	Meeuwig et al. 2005
Larva	Decreased survival	22	Sample size: NA Acclimation temperature: 10–22°C Rate of change: NA Feeding history: NA Control: NA	Laboratory	Meeuwig et al. 2005
Juvenile and adult	Significant increase in abnormalities.	>22	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Moyle et al. 2015
Spawning	Nest building observed	12–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Moyle 2002, cited in Moyle et al. 2015

In Situ, Model, or Other Publication Types

Table 75. *Lampetra tridentate* (Pacific Lamprey) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Nests present (early June)	9–16	Sample size: 49	Other (Research and Restoration Project Annual Report)	Close 2001

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 76. *Lampetra tridentate* (Pacific Lamprey) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	>78%	Sample Size: NA Temperature: 25°C	In situ	Waite and Carpenter 2000

Lepomis gibbosus (Pumpkinseed)

The optimal temperature range of pumpkinseed varies by life stage and is reported broadly between 13–33°C yet most final temperature preferenda are greater than 20°C.The preferred temperature of adult pumpkinseed is on the warmer end of the range—between 26–32°C (multiple references, cited in Hillman et al. 1999; reference not specified in Lyons et al. 2010). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 77. *Lepomis gibbosus* (Pumpkinseed) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Juvenile	Optimal temperature range	13–28	Sample size: 3 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Neophitou and Giapis 1994, cited in Küttel et al. 2002, cited in Souchon and Tissot 2012
Juvenile	Final temperature preferendum	21–33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Optimal temperature range	12–30	Sample size: 18 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Becker et al. 1977 and Beitinger et al. 2000, cited in Souchon and Tissot 2012
Adult	Preferred temperature range	26–31.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Reference not specified in Lyons et al. 2010
Adult	Final temperature preferendum	26–32	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Multiple references, cited in Hillman et al. 1999

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Spawning	Optimal minimum	13	Sample size: 4 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Buslé and Quignard 2001; Wiliamson et al. 1993 in Küttel et al. 2002 and Teletchea et al. 2009, cited in Souchon and Tissot 2012
Not specified	Optimum growth	15–30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Final temperature preferendum	26–31.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Upper avoidance temperature (endpoint was absence)	>31	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Critical thermal maxima (endpoint was not specified)	35.1–37.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Reference not specified in Lyons et al. 2009
Spawning	Upper limit of resistance (endpoint was absence)	25	Sample size: 4 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Neophitou and Giapis 1994 in Küttel et al. 2002, cited in Souchon and Tissot 2012
Not specified	Upper lethal temperature (endpoint was mortality)	28–36.6	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Short-term maximum (endpoint was not specified)	37.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Present	37.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Tolerance of hypoxia ceased (endpoint was loss of equilibrium)	28	Sample size: 8 per species Acclimation temperature: 12–15°C Rate of change: NA Feeding history: Wild-caught fish were not fed, and lab raised fish were fed beef organs 4–5x daily Control: No	Laboratory	Borowiec et al. 2016

In Situ, Model, or Other Publication Types

Table 78. *Lepomis gibbosus* (Pumpkinseed) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile and adult	Present (positively associated with decreasing temperature)	11.3–31	Sample size: 868	In situ	Bhagat and Ruetz 2011
Not specified	Present (peak summer water temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Maximum weekly average tolerance (based on FTDMS database)	29.1	Sample size: NA	Model	Eaton and Scheller 1996
Not specified	Present	22.39	Sample size: NA	Model	Zorn et al. 2009

Dissolved Oxygen

Laboratory and Review Studies

Table 79. ***Lepomis gibbosus*** **(Pumpkinseed) Dissolved Oxygen Data from Laboratory and Review Studies**

Life stage	DO consideration (effect)	DO value (mg/L or % air saturation)	Study design considerations	Study type	Reference
Adult	Hypoxia reduced aerobic swimming performance. (endpoint was swimming performance and loss of equilibrium)	15% air saturation	Sample size: 17 Temperature: 12–15°C Rate of change: Progressive decreases of 10% air saturation every 20 mins until reaching 15% when the chamber was sealed and fish consumed remaining oxygen until reaching loss of equilibrium Feeding history: squid and beef organs fed 4–5x daily; fasted 24h prior to experiment Control: No	Laboratory	Crans et al. 2015
Adult (inferred)	Reduced glycolytic enzymes in normoxic waters	7–8	Sample size: NA Temperature: 20–22°C Rate of change: NA Feeding history: ad libitum Control: Yes	Laboratory	Davies et al. 2011
Adult (inferred)	Loss of equilibrium	0.98	Sample size: 20 Acclimation temperature: 5–12°C Experiment temperature: 5°C Rate of change: progressive reduction over 16h Feeding history: fed maintenance ration Control: Yes	Laboratory	Farwell et al. 2007

In Situ, Model, or Other Publication Types

Table 80. *Lepomis gibbosus* (Pumpkinseed) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L or % air saturation)	Study design considerations	Study type	Reference
Juvenile and adult	Present (positively associated with increasing DO)	6.63–14.51	Sample size: 868	In situ	Bhagat and Ruetz 2011
Not specified	Present	>64%	Sample Size: NA Temperature: 23°C	In situ	Waite and Carpenter 2000

Micropterus dolomieu (Smallmouth Bass)

The optimal temperature range for smallmouth bass varies by life stage but is generally between 15.5–32°C. The optimal growth temperature is likely to be on the higher end of this range between 26–32°C (Eaton et al. 1995a and 1995b; multiple references, cited in Hillman et al. 1999). Welch et al. (2011) reported that optimal habitats for smallmouth bass have greater than 6 mg/L DO.

Temperature

Laboratory and Review Studies

Table 81. *Micropterus dolomieu* (Smallmouth Bass) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Juvenile	Optimum growth	26–28.2	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Final temperature preferendum	23–31.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Optimum growth	26–29	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Final temperature preferendum	21–31	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Multiple references, cited in Hillman et al. 1999

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Adult	Preferred temperature	30–31.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Reference not specified in Lyons et al. 2009
Not specified	Preferred temperature range	15.56–21.11	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference Not specified, cited in Bell 1990
Not specified	Final temperature preferendum	20–31.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Optimum growth	26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Present	20.3–31	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Maximum weekly average temperature	29–33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Upper avoidance temperature (endpoint was absence)	35	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999.
Juvenile	Short-term maximum	35	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Upper lethal temperature (endpoint was mortality)	35	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Ultimate upper incipient lethal temperature (endpoint was mortality)	37	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Present	>28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Bevelhimer and Adams 1991, cited in Armour 1993
Adult	Present	13–31	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Maximum weekly average temperature	29–33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Upper lethal temperature (endpoint was mortality)	32.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Short-term maximum	35	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Critical thermal maxima (endpoint was not specified)	36.3–36.9	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Reference not specified in Lyons et al. 2010
Adult	Critical thermal maximum (endpoint was loss of equilibrium)	36.9	Sample size: 8 Acclimation temperature: 26°C Rate of change: 2°C per hour Feeding history: Fed daily and fasted 24h prior to treatments Control: No	Laboratory	Smale and Rabeni 1995
Spawning	Spawning onset observed	11.6	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Phelan and Philip (1990), cited in Armour 1993

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Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning observed	15	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Langhurst and Schoenike (1990), cited in Armour 1993
Not specified	Selected temperature when food was present	31	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Bevelhimer and Adams 1991, cited in Armour 1993
Not specified	Maximum weekly average temperature	29	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper avoidance temperature (endpoint was absence)	33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper lethal temperature (endpoint was mortality)	29.4–35	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Short-term maximum	36.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Critical thermal maximum (endpoint was loss of equilibrium)	36.9	Sample size: 8 Acclimation temperature: 26°C Rate of change: 0.017°C per min. Feeding history: NA Control: No	Review	Smale and Rabeni 1995, cited in Beitinger et al. 2000

In Situ, Model, or Other Publication Types

Table 82. *Micropterus dolomieu* (Smallmouth Bass) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Juvenile	Maximum growth temperature	28.2	Sample size: NA	Model	Eaton et al. 1995b
Not specified	Optimal growth temperature	22	Sample size: NA	Model	Zweifel et al. 1999, cited in Middaugh et al. 2018
Not specified	Maximum growth temperature	30.6–31.3	Sample size: NA	In situ	Eaton et al. 1995a
Eggs/ embryos	Nest survival rate increased	>15	Sample size: 32	In situ	Kaemingk et al. 2011
Juvenile	Catch per unit effort ranged 0.03–0.41	17.5–21.5	Sample size: 325	Model	Middaugh and Magoulick 2018
Juvenile and adult	Present (positively associated with decreasing temperature)	16.8–31	Sample size: 51	In situ	Bhagat and Ruetz 2011
Adult	Maximum 95% weekly temperature (above this temperature growth was negatively impacted)	29.3–31	Sample size: 88	Model	Stefan et al. 1994
Adult	Maximum 99% weekly temperature	30.6–31.3	Sample size: 88	Model	Stefan et al. 1994
Spawning	Spawning initiated	15	Sample size: NA	In situ	Rubenson and Olden 2017
Not specified	Present	19.4–23.3	Sample size: NA	In situ	Rubenson and Olden 2017
Not specified	Present	23.3	Sample size: NA	Model	Zorn et al. 2009
Not specified	Present	22.1	Sample size: NA	In situ	Hinz et al. 2011
Not specified	Present	18.1–19.1	Sample size: 138	In situ	Feyrer and Healey 2003[14]
Not specified	Present (peak summer water temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Maximum weekly average tolerance (based on FTDMS database)	29.5	Sample size: NA	Model	Eaton and Scheller 1996
Not specified	Maximum 95% weekly temperature	29.3	Sample size: NA	Model	Eaton et al. 1995b
Not specified	Estimated 95th percentile weekly mean temperature	29.5	Sample size: 209	In situ	Eaton et al. 1995a
Not specified	Reduced growth and relative weight compared to largemouth bass	7.13–13.48	Sample size: NA	In situ	Mueller and Congdon 2002
Not specified	Upper temperature tolerance limit (endpoint was not specified)	35	Sample size: NA	Model	Eaton et al. 1995b
Not specified	Upper thermal tolerance	28.9	Sample size: present at 458 of the 1559 sites sampled	Model	Walters et al. 2018
Not specified	Warming tolerance	8.6	Sample size: present at 458 of the 1559 sites sampled	Model	Walters et al. 2018
Not specified	Upper weekly mean temperature threshold (endpoint was positive growth and viability)	27	Sample size: NA	Model	Reference not specified in Middaugh et al. 2018
Not specified	Mortality	32.5–39.5	Sample size: NA	Model	Mundahl 1990

Dissolved Oxygen

Laboratory and Review Studies

Table 83. *Micropterus dolomieu* (Smallmouth Bass) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L or torr)	Study design considerations	Study type	Reference
Juvenile	Critical DO concentration (endpoint was ceased ventilation and opercular movement)	1.19 (1.08–1.29)	Sample size: 10 Temperature: NA Rate of change: NA Feeding history: daily ration corresponded to amount finished within a few minutes Control: No	Laboratory	Smale and Rabeni 1995
Adult	Hypoxia reduced ventilation and cardiac capacity (endpoints were respiratory and cardiac output, plus mortality.)	90, 60, 45 Torr	Sample size: 7 Temperature: 20±2°C Rate of change: NA Feeding history: NA Control: Yes	Laboratory	Furimsky et al. 2003
Not specified	Suboptimal growth	5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Welch and Jacoby 2004, cited in Welch et al. 2011
Not specified	Survival	2–3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Welch and Jacoby 2004, cited in Welch et al. 2011

In Situ, Model, or Other Publication Types

Table 84. *Micropterus dolomieu* (Smallmouth Bass) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L or % saturation)	Study design considerations	Study type	Reference
		Optimal and preferred values			
Not specified	Optimal habitat	>6	Sample Size: NA Temperature: <27°C	In situ	Welch et al. 2011
Juvenile and adult	Present	6.63–14.51	Sample Size: 51 Temperature: 16.8–31°C	In situ	Bhagat and Ruetz 2011

Life stage	DO consideration (effect)	DO value (mg/L or % saturation)	Study design considerations	Study type	Reference
Not specified	Present	7.3–9.4	Sample Size: NA Temperature: 11.9°C (surface) and 4.3°C (depth)	In situ	Mueller et al. 2002
Not specified	Present	6.1–7.7	Sample Size: NA Temperature: 20.4°C (surface) and 4.6°C (depth)	In situ	Mueller et al. 2002
Not specified	Present	3.7–4.9	Sample Size: NA Temperature: 9.9°C (surface) and 5°C (depth)	In situ	Mueller et al. 2002
Not specified	Present	7.6–8.9	Sample Size: NA Temperature: 18.1±5.3°C to 19.3±5.1°C	In situ	Feyrer and Healey 2003[14]
Not specified	Present	78%	Sample Size: NA Temperature: 25°C	In situ	Waite and Carpenter 2000
Not specified	Suboptimal habitat	≤5	Sample Size: NA Temperature: <29°C	In situ	Welch et al. 2011

Morone chrysops (White Bass)

The preferred temperature for adult white bass is between 27.8–31°C (reference not specified in Lyons et al. 2009). Bell (1990, reference not specified) reported a preferred temperature range of 12.8–15.6°C for migration occurring from late December through March, as well as a preferred spawning temperature range of 15.6–23.9°C. No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 85. *Morone chrysops* (White Bass) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Adult	Preferred temperature for December-March migration	12.8–15.6	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Bell 1990
Adult	Preferred temperature	27.8–31	Sample size: NA Acclimation temperature: NA Rate of change: NA	Laboratory	Reference not specified in Lyons et al. 2009

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Spawning	Preferred temperature	15.6–23.9	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Bell 1990
Adult	Critical thermal maxima	35.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Reference not specified in Lyons et al. 2009.

In Situ, Model, or Other Publication Types

Table 86. *Morone chrysops* (White Bass) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Upper temperature tolerance limit	33.5	Sample size: 237	Model	Stefan et al. 1994
Adult	Maximum 95% weekly temperature (above this temperature growth was negatively impacted)	31.2–31.7	Sample size: 237	Model	Stefan et al. 1994
Adult	Maximum 99% weekly temp	31.7–32.2	Sample size: 237	Model	Stefan et al. 1994
Not specified	Maximum weekly average tolerance (based on FTDMS database)	31.4	Sample size: NA	Model	Eaton and Scheller 1996
Not specified	95th percentile weekly mean temperatures (based on FTDMS database)	31.4	Sample size: 237	In situ	Eaton et al. 1995a

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Morone saxatilis (Striped Bass)

Bell (1990) reported a preferred temperature range of 15.6–18.3°C for an unspecified life stage of striped bass. Models by multiple sources indicate that striped bass occupy a preferred temperature range of 19–29°C. Optimal habitats for striped bass, with consistent growth, have DO concentrations between 4–8 mg/L (Singkran and Bain 2008; Brandt et al. 2009).

Temperature

Laboratory and Review Studies

Table 87. *Morone saxatilis* (Striped Bass) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Not specified	Preferred temperature range	15.56–18.33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Bell 1990.
Not specified	Critical thermal maximum (endpoint was onset of muscular spasms)	31.6	Sample size: 3 Acclimation temperature: 10 Rate of change: 1°C per min. Feeding history: NA Control: NA	Review	Lutterschmidt and Hutchison 1997, cited in Beitinger et al. 2000

In Situ, Model, or Other Publication Types

Table 88. *Morone saxatilis* (Striped Bass) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Juvenile	Preferred thermal range (optimal habitat preference index = 1)[24]	22.1–27	Sample size: NA	Model	Singkran and Bain 2008
Juvenile	Preferred thermal range compared to temperatures ≤22 (habitat	27.1–29	Sample size: NA	Model	Singkran and Bain 2008

[24] The model looked at 5 different temp ranges and calculated a preference index (PI) between 0 and 1 for each range. The higher the PI value, the higher the species preference is for that temperature range.

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
	preference index = 0.84)[24]				
Juvenile	Optimal growth	15–25	Sample size: NA	Model	Dietrich and Fulford 2012
Juvenile and adult	Optimal growth rate	19–20	Sample size: NA Feeding history: Unlimited prey supply	Model	Brandt 1993
Juvenile and adult	Peak probability of occurrence	19 (14–24)	Sample size: NA Feeding history: Different prey densities at different temperature fronts were modeled	Model	Brandt 1993
Juvenile and adult	Optimal temperature for growth rate potential (-7.96x10[4] grams/day)	10.23	Sample size: 1205–3231 Feeding history: Consumption rate in each grid cell along a transect was a function of the striped bass mass, prey fish biomass, water temperature, and DO concentrations	Model	Costantini et al. 2008
Adult	Preferred thermal range (optimal habitat preference)	22.1–27	Sample size: NA	Model	Singkran and Bain 2008
Not specified	Thermal niche	24–28	Sample size: NA Rate of change: 1°C change in aquatic temperature over year modeled	Model	Coutant 1990
Not specified	Thermal niche	Thermal niche: 19–23 Broader range: 17–25	Sample size: NA Rate of change: 1°C change in aquatic temperature over year modeled	Model	Coutant 1990
Juvenile	Negative growth rate and reduced consumption	23–27	Sample size: NA	Model	Dietrich and Fulford 2012
Juvenile and adult	Food consumption stopped	>25	Sample size: NA Feeding history: Different prey densities at different temperature fronts were modeled	Model	Brandt 1993
Juvenile and adult	The ability of striped bass to consume food increases from about 1% body weight per day	5–25	Sample size: NA Feeding history: Different prey densities at different temperature fronts were modeled	Model	Brandt 1993

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
	at low temperatures to a maximum of 3.3% body weight per day at 19–21°C.				
Juvenile and adult	Growth rate potential ($1.09x10^{-3}$ – $2.64x10^{-3}$ grams/day)	13.21–24.96	Sample size: 1205–3231 Feeding history: Consumption rate in each grid cell along a transect was a function of the striped bass mass, prey fish biomass, water temperature, and DO concentrations	Model	Costantini et al. 2008
Juvenile and adult	Approx. zero growth rate	≤5	Sample size: NA	Model	Dietrich and Fulford 2012
Juvenile and adult	Negative growth rate	30	Sample size: NA	Model	Dietrich and Fulford 2012
Juvenile and adult	Present	6.2–29.8	Sample size: 100 juveniles, 111 adults	In situ	Bradley et al. 2018
Adult	Mortality: >90% in 1 year	≥29	Sample size: 1000–3000	In situ	Groner et al. 2018
Adult	Survival:75% at 26°C; 25% at 29°C	26.2–28.3	Sample size: 1000–3000	In situ	Groner et al. 2018
Adult	Present	7.2–29.2	Sample size: 14	In situ	Kraus et al. 2015
Adult	Absent even with optimal DO	23–25.1	Sample size: 48	In situ	Young and Isely 2002
Adult	Present	<20	Sample size: 36	In situ	Sammons and Glover 2013
Adult	Present	14.4–25.1	Sample size: NA	In situ	Young and Isely 2002
Adult	Absent	27.1–29	Sample size: NA	Model	Singkran and Bain 2008
Adult	Absent	>25	Sample size: 36	In situ	Sammons and Glover 2013
Adult	Present (stress responses at higher temperature values)	>26	Sample size: 51	In situ	Jackson and Hightower 2001
Not specified	Absent	<5	Sample size: NA Rate of change: 1°C change in aquatic temperature over year modeled	Model	Coutant 1990
Not specified	Absent	>25	Sample size: NA Rate of change: 1°C change	Model	Coutant 1990

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			in aquatic temperature over year modeled		
Not specified	Present	18.1–19.3	Sample size: 5,043 (across all sites)	In situ	Feyrer and Healey 2003[14]
Not specified	Negative relationship with hepatosomatic index (HSI)	1.27–14.97	Sample size: 714	In situ	Schloesser and Fabrizio 2019

Dissolved Oxygen

Laboratory and Review Studies

Table 89. ***Morone saxatilis*** **(Striped Bass) Dissolved Oxygen Data from Laboratory and Review Studies**

Life stage	DO consideration (effect)	DO value (mg/L or % air saturation)	Study design considerations	Study type	Reference
Optimal and preferred values					
Juvenile	Highest growth	8	Sample size: 60, 3–8 per treatment Temperature: 20, 23, 27, and 30°C Rate of change: static Feeding history: ad libitum; fasted 24h prior to experiment Control: No	Laboratory	Brandt et al. 2009
Juvenile	Increased consumption at higher DO levels	2–8	Sample size: 60, 3–8 per treatment Temperature: 20, 23, 27, and 30°C Rate of change: static Feeding history: ad libitum; fasted 24h prior to experiment Control: No	Laboratory	Brandt et al. 2009
Eggs/ embryos	High mortality rate or behavioral changes	<3.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Dove and Nyman 1995 and Bain and Bain 1982, cited in the Patrick Center for Environmental Research 2018
Larva	High mortality rate or behavioral changes	< 3.5 requirement	Sample size: NA Acclimation temperature: NA	Review	Dove and Nyman 1995 and Bain and Bain 1982, cited in

			Rate of change: NA Feeding history: NA Control: NA		the Patrick Center for Environmental Research 2018
Juvenile	High mortality rate or behavioral changes	<3.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Dove and Nyman 1995 and Bain and Bain 1982, cited in the Patrick Center for Environmental Research 2018
Juvenile	No growth or negative growth	2–4	Sample size: 60, 3–8 per treatment Temperature: 20, 23, 27, and 30°C Rate of change: static Feeding history: ad libitum; fasted 24h prior to experiment Control: No	Laboratory	Brandt et al. 2009
Juvenile	Consumption decreased	2	Sample size: 60, 3–8 per treatment Temperature: 20, 23, 27, and 30°C Rate of change: static Feeding history: ad libitum; fasted 24h prior to experiment Control: No	Laboratory	Brandt et al. 2009
Juvenile	Reduced feed utilization under hypoxia	23%	Sample size: 30 Temperature: 22.6°C Rate of change: NA Feeding history: fed ad libitum for 30 min. Control: No	Laboratory	Green et al. 2015
Juvenile	Reduced swim performance under hypoxia	20% (hypoxia)	Sample size: 15 Temperature: 20°C Rate of change: progressively lowered during the second hour to 22:9 air saturation (AS; equivalent to 64:450:8 µmol O_2/L). Feeding history: ad libitum; fasted for 24–48h prior to experiment Control: No	Laboratory	Kraskura and Nelson 2018

Juvenile	Loss of equilibrium (one mortality occurred)	1.42	Sample size: 12 Temperature: 25°C Rate of change: NA Feeding history: ad libitum 2x daily Control: Yes	Laboratory	Dixon et al. 2017
Juvenile	No aquatic surface respiration[25]	1.17–1.42	Sample size: 12 Temperature: 25°C Rate of change: NA Feeding history: ad libitum 2x daily Control: Yes	Laboratory	Dixon et al. 2017
Adult	High mortality rate or behavioral changes	<3.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Dove and Nyman 1995 and Bain and Bain 1982, cited in the Patrick Center for Environmental Research 2018
Adult	Lowest LC50 (endpoint is mortality)	1.1–1.6	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Breitburg et al. 2001, Pihl et al. 1991, Miller et al. 2002, and USEPA 2000, cited in Batiuk et al. 2009.
Not specified	Reduced growth and consumption	<4.5	Sample size: NA Temperature: 8–33°C Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified, cited in Hycik et al. 2017.
Not specified	Reduced growth	<3–4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Brandt et al. 1998, cited in Batiuk et al. 2009

In Situ, Model, or Other Publication Types

Table 90. *Morone saxatilis* (Striped Bass) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
		Optimal and preferred values			
Juvenile	Optimal habitat preference	4.6–6	Sample Size: 50,000 Temperature: NA	Model	Singkran and Bain 2008
Adult	Optimal habitat preference	4.6–6	Sample Size: 50,000 Temperature: NA	Model	Singkran and Bain 2008

[25] Summarized for multiple groups of fish based on size.

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Juvenile	Negative growth rate	<2	Sample Size: NA Temperature: ≤20°C	Model	Dietrich and Fulford 2012
Juvenile	Negative growth rate	<4	Sample Size: NA Temperature: >20°C	Model	Dietrich and Fulford 2012
Juvenile	Absent	<2	Sample Size: 14 Temperature: >25°C	In situ	Kraus et al. 2015
Juvenile and adult	Mortality	<0.5–2	Sample Size: 9,854 Temperature: 14–27°C	In situ	Rice et al. 2013
Adult	Absent	<2.3–4	Sample Size: 48 Temperature: NA	In situ	Young and Isely 2002
Adult	Absent	<1.6	Sample Size: 36 Temperature: <25°C	In situ	Sammons and Glover 2013
Adult	Absent	<2	Sample Size: 51 Temperature: NA	In situ	Jackson and Hightower 2001
Not specified	Present	7.6–8.9	Sample Size: 5,043 (across all locations) Temperature: 18.1±5.3°C to 19.3±5.1°C	In situ	Feyrer and Healey 2003[14]
Not specified	Suboptimal habitat	<5	Sample Size: NA Temperature: <24°C	In situ	Welch et al. 2011
Not specified	Present	7.32–13.54	Sample Size: 0.25–5.71 per 100 m^2 Temperature: 1.27–14.97°C	In situ	Schloesser and Fabrizio 2019

Mylocheilus caurinus (Peamouth)

The optimal temperature for peamouth is 21.3°C (Beauchamp et al. 1995, Godfrey 1955, Narver 1967, and Ricker 1952, cited in Roberge et al. 2002). Peak spawning is between 12–15°C (Gray and Dauble 2001). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 91. *Mylocheilus caurinus* (Peamouth) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Juvenile	Optimal temperature	21.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Beauchamp et al. 1995, Godfrey 1955, Narver 1967, and Ricker 1952, cited in Roberge et al. 2002
Not specified	Upper lethal temperature	27	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 92. *Mylocheilus caurinus* (Peamouth) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Spawning	Peak spawning	12–15	Sample size: NA	In situ	Gray and Dauble 2001
Spawning	Spawning initiated	10–11	Sample size: NA	In situ	Gray and Dauble 2001
Not specified	Present (peak summer water temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Absent (average maximum summer temperature)	19.6	Sample size: 36 (of 48 sites)	Model[11]	Porter et al. 2000
Not specified	Present (average maximum summer temperature)	21	Sample size: 12 (of 48 sites)	Model[11]	Porter et al. 2000

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 93. ***Mylocheilus caurinus*** **(Peamouth) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types**

Life stage	DO consideration (effect)	DO value (% air saturation	Study design considerations	Study type	Reference
Not specified	Present	78%	Sample Size: NA Temperature: 25°C	In situ	Waite and Carpenter 2000

Oregonichthys crameri (Oregon Chub)

No optimal temperature or DO concentration values for Oregon chub were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 94. ***Oregonichthys crameri*** **(Oregon Chub) Temperature Data from Laboratory and Review Studies**

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning observed	16–28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	USEPA 1998
Spawning	Spawning observed	16.5–20.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	USEPA 1998
Spawning (inferred)	Maximum lethal water temperature (endpoint was mortality)	31	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	USEPA 1998

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Perca flavescens (Yellow Perch)

Optimal growth temperatures for yellow perch vary by life stage. Hillman et al. (1999) cited multiple references that reported the optimum growth temperature of adults (13–20°C) to be lower than juveniles (26–30°C) yet the final temperature preferenda overlap between the two life stages. Hillman et al. (1999) also reported the optimum temperature range as 8–27°C but did not specify the life stage. In two studies using models, Magnuson et al. (1990) reported the thermal niche of juveniles to be 23°C and Jansen and Hesslein (2004) reported the upper thermal range of adults to be between 19–23°C. No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 95. *Perca flavescens* (Yellow Perch) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Juvenile	Final temperature preferendum	12.2–27	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Optimum growth temperature	26–30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Optimum growth temperature	13–20	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Final temperature preferendum	17.6–27	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Optimum temperature range	8–27	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Final temperature preferendum	12.2–26.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999.

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Eggs/ embryos	Hatching (within 8 to 10 days)	8.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Robillard and Marsden 2001, cited in Roberge et al. 2002
Juvenile	Present	11–31	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Maximum weekly average temperature	29	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Upper avoidance temperature	25–26.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Upper thermal tolerance limit (endpoint was not specified)	33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Ultimate upper incipient lethal temperature (endpoint was mortality)	29.2–35	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Present	10–26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Maximum weekly average temperature	29	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Upper lethal temperature (endpoint was mortality)	21–32.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Zero net growth	31	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Multiple references, cited in Hillman et al. 1999

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Not specified	Maximum weekly average temperature	29	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper lethal temperature (endpoint was mortality)	25–33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper lethal temperature (endpoint was mortality)	25–29.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reported in Hillman et al. 2000
Not specified	Upper critical range (endpoint was not specified)	23–36	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper thermal tolerance limit (endpoint was not specified)	30–33.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999.
Not specified	Short-term maximum (endpoint was not specified)	35	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 96. *Perca flavescens* (Yellow Perch) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Juvenile	Thermal niche	23	Sample size: NA Acclimation temperature: NA	Model	Magnuson et al. 1990
Not specified	Good-growth temperature (lower to upper)	17.7–28.1	Sample size: NA	Model	Eaton et al. 1995 and Stefan et al. 1993, cited in Fang et al. 2004

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Maximum growth temperature	29.4–30.6	Sample size: NA	Model	Eaton et al. 1995b
Larva	Present	14.2–19.8	Sample size: 30	In situ	Cornell University 2015
Juvenile	Present	9.9–28.3	Sample size: Captured in 79–92% of all net sets in each year	In situ	Burdick et al. 2008
Juvenile	Upper temperature tolerance limit (endpoint was not specified)	33	Sample size: NA Acclimation temperature: NA	Model	Eaton et al. 1995b
Juvenile and adult	Present (negative association with decreasing temperature)	11.3–31	Sample size: 2472 Acclimation temperature: NA	In situ	Bhagat and Ruetz 2011
Juvenile and adult	Present	<29	Sample size: 81 caught in drowned river mouths and 18,801 in coastal fringing wetlands	In situ	Parker et al. 2012
Adult	Thermal range: Broad niche for thermal habitat	16–26	Sample size: NA	Model	Jansen and Hesslein 2004
Adult	Thermal range: narrow niche for thermal habitat	19–23	Sample size: NA	Model	Jansen and Hesslein 2004
Adult	Upper temperature tolerance limit for growth	33	Sample size: 54	Model	Stefan et al. 1994
Adult	Maximum 95–99% weekly temperature	29.4–30.6	Sample size: 54	Model	Stefan et al. 1994
Not specified	Present	21.72	Sample size: NA	Model	Zorn et al. 2009
Not specified	Present (peak summer water temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Maximum weekly average tolerance (based on	29.1	Sample size: NA	Model	Eaton and Scheller 1996

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
	FTDMS database)				
Not specified	Estimated 95th percentile weekly mean temperature	29.1	Sample size: 64	In situ	Eaton et al. 1995a
Not specified	Upper habitat temperature limit	28.9	Sample size: NA	Model	Eaton et al. 1995 and Stefan et al. 1993, cited in Fang et al. 2004
Not specified	Upper thermal tolerance (endpoint was fish persistence)	25	Sample size: present at 458 of the 1,559 sites sampled	Model	Walters et al. 2018
Not specified	Warming tolerance (endpoint was fish persistence)	4.2	Sample size: present at 458 of the 1,559 sites sampled	Model	Walters et al. 2018

Dissolved Oxygen

Laboratory and Review Studies

Table 97. *Perca flavescens* (Yellow Perch) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Juvenile	No effect on movement or foraging	2.7–4.5	Sample size: 20 per trial Temperature: 15°C Rate of change: Gradually decreasing the DO concentration in a tank from normoxic to hypoxic over 30 min and maintaining the target level for 30 min. Feeding history: 20 pellets of slow sink food 1x daily Control: Yes	Laboratory	Almeida et al. 2017
Juvenile	No effect on hemoglobin concentration and gene expression.	2.1–9.6	Sample size: 72 Temperature: 15°C Rate of change: Gradually decreasing the DO concentration in a tank from normoxic (9.6 mg/L) to hypoxic	Laboratory	Almeida et al. 2017

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			(2.1 mg/L) over 30 min and maintaining the target level for 30 min. Feeding history: 20 pellets of slow sink food 1x daily Control: Yes		
Juvenile	No impact on consumption, growth, hemoglobin concentration, gene and expression	2.5–9	Sample size: 72 Temperature: 15°C Rate of change: Gradually decreasing the DO concentration in a tank from normoxic to hypoxic over 30 min. and maintaining the target level for 30 min. Feeding history: 20 pellets of slow sink food 1x daily Control: Yes	Laboratory	Almeida et al. 2017
Juvenile	Growth increase (0.25% at 2 mg/L)	2	Sample size: 72 Temperature: 11°C Rate of change: NA Feeding history: various feeding regimes were used for different trials Control: Yes	Laboratory	Roberts et al. 2011
Juvenile	Growth declined (0.15%)	2	Sample size: 72 Temperature: 20°C Rate of change: NA Feeding history: various feeding regimes were used for different trials Control: Yes	Laboratory	Roberts et al. 2011
Juvenile	Growth increased	5–8	Sample size: 72 Temperature: 20°C Rate of change: NA Feeding history: various feeding regimes were used for different trials Control: Yes	Laboratory	Roberts et al. 2011
Juvenile	Growth (biomass/day) decreased (1–1.25% and ~25%)	2–5	Sample size: 72 Temperature: 26°C Rate of change: NA Feeding history: various feeding regimes were used for different trials Control: Yes	Laboratory	Roberts et al. 2011
Juvenile	No change in growth	8	Sample size: 72 Temperature: 26°C Rate of change: NA	Laboratory	Roberts et al. 2011

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			Feeding history: various feeding regimes were used for different trials Control: Yes		
Not specified	Reduced consumption rate	2	Sample size: 50 Temperature: 20°C Rate of change: Two static oxygen treatments (high: 8 mg/L and low: 2 mg/L), two diurnally fluctuating oxygen treatments (high-night/low-day O_2 and low night/high-day O_2) and one rapidly fluctuating treatment. Feeding history: slow sinking pellets for 30 days; fasted for 48h prior to experiment Control: No	Laboratory	Roberts et al. 2012
Not specified	Present	>9.8	Sample size: NA Temperature: <16.11°C Rate of change: NA Feeding history: NA Control: NA	Review	Koza 1998, cited in Donabauer 2011

In Situ, Model, or Other Publication Types

Table 98. *Perca flavescens* (Yellow Perch) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Larva	Present	8.8–10.5	Sample Size: NA Temperature: 16.5°C	In situ	Cornell University 2015
Juvenile	Present	2–12	Sample Size: NA Temperature: 9.8–28.6°C	In situ	Burdick et al. 2008
Juvenile and adult	Present	1.1–9.5	Sample Size: 18,882 Temperature: 14.3–27°C	In situ	Parker et al. 2012
Juvenile and adult	Consumption of smaller midges	≤2	Sample Size: 433 Temperature: NA	In situ	Goto et al. 2017
Not specified	Absent	0.9–2.5	Sample Size: 646 Temperature: 15.4°C	In situ	Roberts et al. 2009
Not specified	Present	2.58–10.09	Sample Size: 89 Temperature: NA	In situ	Weinke and Biddanda 2018

Ptychocheilus oregonensis (Northern Pikeminnow)

The optimal temperature range for northern pikeminnow is between 16.1–24.4°C (multiple references, cited in Hillman et al. 1999). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 99. *Ptychocheilus oregonensis* (Northern Pikeminnow) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Not specified	Optimal temperature range	16.1–24.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Final temperature preferendum	16.1–22.8	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper lethal temperature (endpoint was mortality)	29.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper incipient lethal temperature (endpoint was mortality)	29	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 100. *Ptychocheilus oregonensis* (Northern Pikeminnow) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning observed	14–18.5	Sample size: NA	In situ	Gray and Dauble 2001
Not specified	Absent (average maximum summer temperature)	18.9	Sample size: 29 (of 48 sites)	Model[11]	Porter et al. 2000

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present (average maximum summer temperature)	21.4	Sample size: 19 (of 48 sites)	Model[11]	Porter et al. 2000

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Rhinichthys cataractae (Longnose Dace)

No optimal temperature or DO concentration values for longnose dace were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 101. *Rhinichthys cataractae* (Longnose Dace) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Present	5.4–22.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Critical thermal maxima (endpoint was not specified)	31.4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Lyons et al. 2009
Not specified	Upper lethal temperature (endpoint was not specified)	23.1	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 102. *Rhinichthys cataractae* (Longnose Dace) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning observed	10–16	Sample size: NA	In situ	Gray and Dauble 2001
Spawning	Minimum daily water temperature inversely related to relative gonadal index (Spearman's correlation is -0.6)	4	Sample size: 49	In situ	DeHaven et al. 1992
Spawning	Maximum daily water temperature inversely related to relative gonadal index (Spearman's correlation is -0.75)	16	Sample size: 49	In situ	DeHaven et al. 1992
Not specified	Present	11–25	Sample size: NA	In situ	Ebersole 2001
Not specified	Present	16.8–21.3	Sample size: NA	In situ	Hinz et al. 2011
Not specified	Present	2–19	Sample size: NA	In situ	Thompson et al. 2001
Not specified	Present (average maximum summer temperature)	20.5	Sample size: 19 (of 48 sites)	Model[11]	Porter et al. 2000
Not specified	Present	19.72	Sample size: NA	Model	Zorn et al. 2009
Not specified	Absent (average maximum summer temperature)	19.7	Sample size: 29 (of 48 sites)	Model[11]	Porter et al. 2000
Not specified	Maximum weekly average tolerance (based on FTDMS database)	26.5	Sample size: NA	Model	Eaton and Scheller 1996

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 103. *Rhinichthys cataractae* (Longnose Dace) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	>64%	Sample Size: NA Temperature: 23°C (maximum observed)	In situ	Waite and Carpenter 2000

Rhinichthys falcatus (Leopard Dace)

The optimal temperature for juvenile leopard dace is 21.2°C (reference not specified in Roberge et al. 2002). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 104. *Rhinichthys falcatus* (Leopard Dace) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Juvenile	Optimal temperature	21.2	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Roberge et al. 2002
Adult (inferred)	Present	15–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Penden 1991, cited in Roberge et al. 2002

In Situ, Model, or Other Publication Types

Table 105. *Rhinichthys falcatus* (Leopard Dace) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning observed	10–16	Sample size: NA	In situ	Gray and Dauble 2001
Not specified	Present (average maximum summer temperature)	21.2	Sample size: 14 (of 48 sites)	Model[11]	Porter et al. 2000
Not specified	Absent (average	19.4	Sample size: 34 (of 48 sites)	Model[11]	Porter et al. 2000

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
	maximum summer temperature)				

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Rhinichthys osculus (Speckled Dace)

The optimal temperature range for spawning Speckled Dace is between 14–24°C (reference not specified in Roberge et al. 2002). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 106. *Rhinichthys osculus* (Speckled Dace) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Spawning	Optimal spawning range	14–24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Roberge et al. 2002
Not specified	Critical maximum thermal threshold (endpoint was mortality)	36.0–36.9	Sample size: 4 fish per treatment and 3 replicates Acclimation temperatures: 25°C and 30°C Rate of change: Did not vary by more than 0.28°C per min. within a test Feeding history: Ad libitum; fasted 24h prior to trials Control: No	Laboratory	Carveth et al. 2006
Not specified	Critical maximum thermal threshold (endpoint was permanent loss of equilibrium)	34.4–36.9	Sample size: 4 fish per treatment and 3 replicates Acclimation temperatures: 25°C and 30°C Rate of change: Did not vary by more than 0.28°C per min. within a test Feeding history: Ad libitum;	Laboratory	Carveth et al. 2006

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			fasted 24h prior to trials Control: No		
Not specified	Critical maximum thermal threshold (endpoint was loss of equilibrium and continued flaring opercula)	35.9–37.0	Sample size: 4 fish per treatment and 3 replicates Acclimation temperature: 25°C and 30°C Rate of change: Did not vary by more than 0.28°C per min. within a test Feeding history: Ad libitum; fasted 24h prior to trials Control: No	Laboratory	Carveth et al. 2006
Not specified	Critical maximum thermal threshold (endpoint was initial loss of equilibrium)	34.4–35.8	Sample size: 4 fish per treatment and 3 replicates Acclimation temperature: 25°C and 30°C Rate of change: Did not vary by more than 0.28°C per min. within a test Feeding history: Ad libitum; fasted 24h prior to trials Control: No	Laboratory	Carveth et al. 2006
Not specified	Absent	25.2–28.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Scoppettone et al. 2011, cited in Moyle et al. 2015
Not specified	Active	>4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Moyle 2002 and Robinson and Childs 2001, cited in Moyle et al. 2015
Not specified	Absent	>28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Personal communications 2009, cited in Moyle et al. 2015
Not specified	Absent	>29	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Personal communications 2013, cited in Moyle et al. 2015
Not specified	Present	23.4–24.8	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Scoppettone et al. 2011, cited in Moyle et al. 2015
Not specified	Present	<20	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Moyle et al. 1995, cited in Moyle et al. 2015

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		
Not specified	Tolerance range	26–28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Moyle et al. 2015
Not specified	Present	10–32	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Present	18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Personal communications with Alan Mundall 1998, cited in USEPA 1998
Adult (inferred)	Critical thermal maxima	32.4	Sample size: 10 Acclimation temperature: 20°C Rate of change: 0.3°C per min. Feeding history: Satiated Control: Yes	Laboratory	Castleberry and Cech 1992
Spawning	Initiated spawning	18–24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Kaya 1991, cited in Roberge et al. 2002

In Situ, Model, or Other Publication Types

Table 107. *Rhinichthys osculus* (Speckled Dace) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning observed	10–16	Sample size: NA	In situ	Gray and Dauble 2001
Not specified	Present (peak summer water temperatures	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Present	11–25	Sample size: NA	In situ	Reference not specified in Ebersole 2001.

Dissolved Oxygen

Laboratory and Review Studies

Table 108. *Rhinichthys osculus* (Speckled Dace) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Not specified	Present	5–8.6	Sample size: NA Temperature Amargosa Canyon: 23.4–24.8°C Temperature Willow Creek: 21–28°C Rate of change: NA Feeding history: NA Control: NA	Review	Scoppettone et al. 2011 and Williams et al. 1982, cited in Moyle et al. 2015
Adult (inferred)	Critical oxygen minima (endpoint was permanent loss of equilibrium)	0.8 (0.5–1.1)	Sample size: 10 Temperature: 20°C Rate of change: decrease of 1.25 torr per min. Feeding history: ad libitum Control: Yes	Laboratory	Castleberry and Cech 1992

In Situ, Model, or Other Publication Types

Table 109. *Rhinichthys osculus* (Speckled Dace) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	>64–78	Sample Size: NA Temperature: 23–25°C (maximum observed)	In situ	Waite and Carpenter 2000[14]

Richardsonius balteatus (Redside Shiner)

The optimal temperature range for adult redside shiner is between 21-28°C (reference not specified in Roberge et al. 2002). Roberge et al. (2002) also reports the optimal temperature range for spawning to be 14.5–18°C. No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 110. *Richardsonius balteatus* (Redside Shiner) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Adult	Optimal temperature range	21–28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Roberge et al. 2002
Spawning	Optimal temperature range	14.5–18	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in Roberge et al. 2002
Not specified	Present	6.7–23.9	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Not specified	Upper lethal temperature limit (endpoint was mortality)	25–30.3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 111. *Richardsonius balteatus* (Redside Shiner) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Spawning observed	10–18	Sample size: NA	In situ	Gray and Dauble 2001
Not specified	Present (peak summer water temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Present	11–25	Sample size: NA	In situ	Reference not specified in Ebersole 2001
Not specified	Absent (average maximum summer temperature)	18.9	Sample size: 26 (of 48 sites)	Model	Porter et al. 2000

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Present (average maximum summer temperature)	21	Sample size: 22 (of 48 sites)	Model	Porter et al. 2000

Dissolved Oxygen

Laboratory and Review Studies

No laboratory or review studies published in 1990 or later were found for this coolwater species.

In Situ, Model, or Other Publication Types

Table 112. *Richardsonius balteatus* (Redside Shiner) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (% air saturation)	Study design considerations	Study type	Reference
Not specified	Present	>64–78	Sample Size: NA Temperature: 23–25°C (maximum observed)	In situ	Waite and Carpenter 2000[14]

Spirinchus thaleichthys (Longfin Smelt)

No optimal temperature or DO concentration values for longfin smelt were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 113. *Spirinchus thaleichthys* (Longfin Smelt) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile and adult	Present (based on catch data from CDFW[26] from 1995-2015)	16.4 (10–24)	Sample size: 28,382 Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Laboratory	Jeffries et al. 2016
Larva and juvenile	No statistically significant difference in oxygen	14–20	Sample size: 22 Acclimation temperature: 14°C Rate of change: 0.3°C per min.	Laboratory	Jeffries et al. 2016

[26] CDFW - California Department of Fish and Wildlife.

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
	consumption or metabolic rate		Feeding history: NA Control: Yes		
Larva and juvenile	Cellular stress (upregulation of heat shock proteins),	20	Sample size: 8 Acclimation temperature: 14 Rate of change: 0.3°C per min. Feeding history: NA Control: Yes	Laboratory	Jeffries et al. 2016
Larva and juvenile	Upper thermal tolerance (endpoint was loss of equilibrium)	24.8	Sample size: 17 Acclimation temperature: 14 Rate of change: 0.3°C per min. Feeding history: NA Control: Yes	Laboratory	Jeffries et al. 2016

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

No DO studies were found published after 1990 for this coolwater species.

Stizostedion vitreum (Walleye)

The optimal temperature for growth in walleye ranges from 22–28°C in juvenile fish and 20–24°C in adult fish (multiple references, cited in Hillman et al. 1999) and the preferred summer habitat temperature is 20°C (Magnuson et al. 1990). Models by Eaton et al. (1995) and Stefan et al. (1993) indicated good growth temperatures between 18.2–28.2°C. A model by Missaghi et al. (2017) indicated good juvenile growth at DO concentrations greater than 3 mg/L.

Temperature

Laboratory and Review Studies

Table 114. *Stizostedion vitreum* (Walleye) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Optimal and preferred values		
Juvenile	Final temperature preferendum	22–25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Optimum range	20–26	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Optimum growth	22–28	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Adult	Optimum growth	20–24	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Larva	Increased mortality (corresponding to temperature increases of 2–12°C)	16–26	Sample size: 25–35 for each group, 3–6 replicates Acclimation temperature: 14°C Rate of change: 1.5°C per min. Feeding history: NA Control: Yes	Laboratory	Clapp et al. 1997
Juvenile	Present	15–34	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Maximum weekly average temperature	25	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Zero net growth	29–30	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile	Increased mortality (temp. increases > 10°C, final temp. > 30°C)	24–33	Sample size: 10 per experiment, with 3–6 replicates Acclimation temperature: 20°C Rate of change: 1.5°C per min. Duration of exposure: 48 hours Feeding history: Fed fathead minnows and western mosquitofish; fasted 24h prior to trials Control: Yes	Laboratory	Clapp et al. 1997
Juvenile	Increased mortality (temp increases > 8°C or final temp. > 32°C)	26–34	Sample size: 10 per experiment, with 3–6 replicates Acclimation temperature: 24°C Rate of change: 1.5°C per min. Duration of exposure: 48 hours Feeding history: Fed fathead minnows and western mosquitofish; fasted 24h prior to trials Control: Yes	Laboratory	Clapp et al. 1997
Juvenile	Increased mortality	31–33	Sample size: 10 per experiment, with 3–6 replicates Acclimation temperature: 20°C Rate of change: 1.5°C per min. Duration of exposure: 48 hours Feeding history: Fed fathead minnows and western mosquitofish; fasted 24h prior to trials Control: Yes	Laboratory	Clapp et al. 1997
Juvenile	Mortality (acclimation temperature interacted with final temperature)	24–34	Sample size: 10 per experiment, with 3–6 replicates Acclimation temperature: 20 and 24°C Rate of change: 1.5°C per min. Feeding history: Fed fathead minnows and western mosquitofish; fasted 24h prior to trials Control: Yes	Laboratory	Clapp et al. 1997
Juvenile	Mortality (rate of temp. increase influenced mortality)	24–34	Sample size: 10 per experiment, with 3–6 replicates Acclimation temperature: 20 and 24°C Rate of change: 1.5°C per min. Feeding history: Fed fathead minnows and western mosquitofish; fasted 24h prior to trials Control: Yes	Laboratory	Clapp et al. 1997

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Juvenile (inferred)	Critical thermal maximum (endpoint was loss of equilibrium)	34.8–35.0	Sample size: 15 Acclimation temperature: 23°C Rate of change: 1°C per min. Feeding history: Ad libitum BioKyowa Control: Yes	Laboratory	Peterson 1993
Juvenile (inferred)	Critical thermal maximum (endpoint was onset of opercular spasms)	35.8–35.9	Sample size: 15 Acclimation temperature: 23°C Rate of change: 1°C per min. Feeding history: Ad libitum BioKyowa Control: Yes	Laboratory	Peterson 1993
Juvenile	Upper lethal temperature (endpoint was mortality)	31.0–34.1	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999
Juvenile	Upper lethal temperature	31.6	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Multiple references, cited in Hillman et al. 1999

In Situ, Model, or Other Publication Types

Table 115. *Stizostedion vitreum* (Walleye) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Not specified	Preferred summer habitat	20	Sample size: NA	Model	Magnuson et al. 1990
Not specified	Good-growth temperature (lower to upper)	18.2–28.2	Sample size: NA	Model	Eaton et al. 1995 and Stefan et al. 1993, cited in Fang et al. 2004
Juvenile and adult	Present	16.8–31	Sample size: 4	In situ	Bhagat and Ruetz 2011
Not specified	Present (peak summer water temperatures)	21.7–23.3	Sample size: NA	In situ	Barfoot et al. 2002
Not specified	Present	19–28.3	Sample size: NA	In situ	Hinz et al. 2011
Not specified	Present	22.72	Sample size: NA	Model	Zorn et al. 2009

Not specified	Maximum weekly average tolerance (FTDMS database)	29	Sample size: NA	Model	Eaton and Scheller 1996
Not specified	Estimated 95th percentile weekly mean (FTDMS database)	29	Sample size: 102	In situ	Eaton et al. 1995a
Not specified	Upper habitat temperature limit (endpoint was mortality)	29	Sample size: NA	Model	Eaton et al. 1995 and Stefan et al. 1993 cited in Fang et al. 2004
Not specified	Restricted growth criteria	28.2–30.4	Sample size: NA	Model	Stefan et al. 2001, cited in Missaghi et al. 2017
Not specified	Lethal temperature	>30.4	Sample size: NA	Model	Stefan et al. 2001, cited in Missaghi et al. 2017
Not specified	Probability of mortality not exceeding 10, 20, or 30% declined sharply at this threshold	14–18	Sample size: NA	In situ	Schramm et al. 2010

Dissolved Oxygen

Laboratory and Review Studies

Table 116. *Stizostedion vitreum* (Walleye) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
Adult	Survival rate: 85%	2	Sample size: 10 Temperature: 18°C Rate of change: NA Duration of exposure: 8 hours Feeding history: fathead minnow during acclimation Control: Yes	Laboratory	Loomis et al. 2013
Adult	Survival rate: 0%	2	Sample size: 10 Temperature: 18°C Rate of change: NA Duration of exposure: 5 days	Laboratory	Loomis et al. 2013

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Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			Feeding history: fathead minnow during acclimation Control: Yes		
Adult	Survival rate: 80%	5	Sample size: 10 Temperature: 18°C Rate of change: NA Duration of exposure: 8 hours Feeding history: fathead minnow during acclimation Control: Yes	Laboratory	Loomis et al. 2013
Adult	Survival rate: 70%	5	Sample size: 10 Temperature: 18°C Rate of change: NA Duration of exposure: 5 days Feeding history: fathead minnow during acclimation Control: Yes	Laboratory	Loomis et al. 2013
Adult	Survival rate: 80%	12–15	Sample size: 10 Temperature: 18°C Rate of change: NA Duration of exposure: 8 hours Feeding history: fathead minnow during acclimation Control: Yes	Laboratory	Loomis et al. 2013
Adult	Survival rate: 75%	12–15	Sample size: 10 Temperature: 18°C Rate of change: NA Duration of exposure: 5 days Feeding history: fathead minnow during acclimation Control: Yes	Laboratory	Loomis et al. 2013
Not specified	Decreased survival	<2–3	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Welch and Jacoby 2004, cited in Welch et al. 2011
Juvenile (inferred)	Suboptimal growth	<5	Sample size: NA Acclimation temperature: NA Rate of change: NA	Review	Welch and Jacoby 2004, cited in Welch et al. 2011

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
			Feeding history: NA Control: NA		

In Situ, Model, or Other Publication Types

Table 117. *Stizostedion vitreum* (Walleye) Dissolved Oxygen Data from In Situ, Model, or Other Publication Types

Life stage	DO consideration (effect)	DO value (mg/L)	Study design considerations	Study type	Reference
		Optimal and preferred values			
Juvenile (inferred)	Good growth criteria	>3	Sample Size: NA Temperature: 16.3–28.2°C	Model	Missaghi et al. 2017
Larva	Present	11.6–12.5	Sample Size: 1 Temperature: 9.6°C	In situ	Cornell University 2015
Juvenile and adult	Present	0.2–15	Sample Size: 3,870 Temperature: 2.7–25°C	In situ	Pandit et al. 2013
Spawning	Present	10.5	Sample Size: NA Temperature: 6.9°C	In situ	Lowie et al. 2001
Not specified	Present	2.6–10.09	Sample Size: NA Temperature: NA	In situ	Weinke and Biddanda 2018
Juvenile (inferred)	Restricted growth	>3	Sample Size: NA Temperature: <16.3°C	Model	Missaghi et al. 2017
Not specified	Lethal concentration	<3	Sample Size: NA Temperature: NA	Model	Missaghi et al. 2017
Juvenile (inferred)	Stresses on growth and survival	<5	Sample Size: NA Temperature: <24°C	In situ	Welch et al. 2011

Thaleichthys pacificus (Eulachon)

Preferred temperatures for eulachon range between 7.2–8.3°C (reference not specified in USACE 1990) and the species has been found at peak densities between 7–15°C (James et al. 2014, cited in USFWS 2015). Spawning is not limited between 4–8°C (Morrow 1980 and Emmett et al. 1991, cited in Moyle et al. 1995). No optimal DO concentrations were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 118. *Thaleichthys pacificus* (Eulachon) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
		Optimal and preferred values			
Spawning	Limited Spawning	<4 and >8	Sample size: NA Acclimation temperature: NA	Review	Emmett et al. 1991 and Morrow 1980,

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Rate of change: NA Feeding history: NA Control: NA		cited in Moyle et al. 1995
Not specified	Present (preferred temperatures)	7.22–8.33	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in USACE 1990
Eggs/ embryos	Incubation (hatched after 47 days)	8.9	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Howell 2001, cited in Gustafson et al. 2010
Eggs/ embryos	Incubation (hatched within four weeks)	4–5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Hay and McCarter 2000, cited in Roberge et al. 2002
Eggs/ embryos	Incubation (hatched within 19 days)	8.5–11.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Emmett et al. 1991 and Morrow 1980, cited in Moyle et al. 1995
Eggs/ embryos	Incubation (hatched within 30–40 days)	4.4–7.2	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Emmett et al. 1991 and Morrow 1980, cited in Moyle et al. 1995
Spawning	Present	2	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Willson et al. 2006, cited in NOAA 2011
Spawning	Spawning migration observed	0–10	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Willson et al. 2006, cited in Gustafson et al. 2012
Spawning	Spawning run observed	1.6–12.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Spangler et al. 2003, cited in Gustafson et al. 2010
Spawning	Spawning observed	0.5–10.7	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Spangler et al. 2003, cited in Gustafson et al. 2010

Attachment #8: White Sturgeon Literature Review

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Spawning	Onset of Spawning	2.8–6	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Spangler 2002 and Spangler et al. 2003, cited in Gustafson et al. 2010
Spawning	Spawning initiated	>4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Emmett et al. 1991 and Morrow 1980, cited in Moyle et al. 1995
Spawning	Present	4–10	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in WDFW and ODFW 2001
Spawning	Present	4.4–10	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in WDFW and ODFW 2001
Spawning	Present	>6	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Hay et al. 2003, cited in Gustafson et al. 2010
Spawning	Present	1.1–6.5	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Lewis et al. 2002, cited in Gustafson et al. 2010
Not specified	Limited migration	<4	Sample size: NA Acclimation temperature: NA Rate of change: NA Feeding history: NA Control: NA	Review	Reference not specified in WDFW and ODFW 2001

In Situ, Model, or Other Publication Types

Table 119. *Thaleichthys pacificus* (Eulachon) Temperature Data from In Situ, Model, or Other Publication Types

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Optimal and preferred values					
Early life stages	Present (peak densities)	7–15	Sample size: NA	Other (biological opinion)	James et al. 2014, cited in USFWS 2015
Eggs/ embryos	Incubation	14	Sample size: NA	Other (biological opinion)	USFWS 2015
Embryo and larva	Present	5–10	Sample size: NA	In situ	James et al. 2014, cited in ODFW and WDFW 2014[27]
Embryo and larva	Present	6	Sample size: NA	In situ	James et al. 2014 in ODFW and WDFW 2014[27]
Larva	Present	8.4–13.2	Sample size: 1034	In situ	McCarter and Hay 1999
Larva	Threshold for adverse thermal effects	18	Sample size: NA	Other (biological opinion)	USFWS 2015
Larva	Mortality (>1 to 24 hours)	>18	Sample size: NA	Other (biological opinion)	USFWS 2015
Spawning	Present	4–10	Sample size: NA	Other (biological opinion)	Howell et al. 2001, WDFW and ODFW 2001, cited in USFWS 2015
Spawning	Threshold for adverse thermal effects	10	Sample size: NA	Other (biological opinion)	USFWS 2015
Spawning	Spawning migration	>4	Sample size: NA	In situ	Howell et al. 2001

Dissolved Oxygen

No DO studies were found published after 1990 for this coolwater species.

[27] This paper summarizes data from multiple sampling locations and seasons.

Hybrid Species

Hybrid species that were a cross between one or more coolwater fish species of interest were identified. Hybrid species can be bred by hatcheries and introduced into natural waters but can also occur naturally.

Lepomis gibbosus (Pumpkinseed) x *Lepomis macrochirus* (Bluegill)

No optimal temperature or DO concentration values for pumpkinseed x bluegill were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 120. *Lepomis gibbosus* (Pumpkinseed) x *Lepomis macrochirus* (Bluegill) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Not specified	Strong main effects of environmental temperature on resting oxygen consumption rate (MO2), resting critical O2 tension, and partial pressure of oxygen (PO2) at loss of equilibrium. Time to loss of equilibrium under hypoxic conditions increased with temperature	15–28	Sample size: 8 per species Acclimation temperature: 12–15°C Rate of change: NA Feeding history: Wild-caught fish were not fed, and lab raised fish were fed beef organs 4–5x daily Control: No	Laboratory	Borowiec et al. 2016

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

Laboratory and Review Studies

Table 121. *Lepomis gibbosus* (Pumpkinseed) x *Lepomis macrochirus* (Bluegill) Dissolved Oxygen Data from Laboratory and Review Studies

Life stage	DO consideration (effect)	DO value (pressure, kPa)	Study design considerations	Study type	Reference
Not specified	Wild fish generally had lower resting metabolic rates and appeared to be more hypoxia tolerant than lab-acclimated fish, as reflected by significant main effects of acclimation environment on resting rate of oxygen consumption, critical oxygen tension (endpoint was loss of equilibrium)	<4–20	Sample size: 8 to 14 Temperature: 12–15°C Rate of change: Stepwise exposure to progressive hypoxia in which the partial pressure of oxygen was reduced by 2 kPa every 20 min. until reaching 4 kPa when the chamber was sealed until loss of equilibrium Feeding history: Lab acclimated fish were fed squid or beef organs 4–5x per weekly; wild-caught and lab reared fish were fasted 18–24h prior to experiment Control: No	Laboratory	Borowiec et al. 2016

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Hybrid Species—*Morone chrysops* x *Morone saxatilis* (Hybrid Striped Bass)

No optimal temperature or DO concentration values for hybrid striped bass were reported by the sources identified in our literature search.

Temperature

Laboratory and Review Studies

Table 122. *Morone chrysops*x *Morone saxatilis* (Hybrid Striped Bass) Temperature Data from Laboratory and Review Studies

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
Adult	Critical thermal maxima (endpoint was complete loss of equilibrium)	28–40.3	Sample size: 4 or 5 Acclimation temperature: 6.5–33.1°C (constant temperature within this range) Rate of change: 0.3°C per min.	Laboratory	Woiwode and Adelman 1992

Life stage	Temperature consideration (effect)	Temp (°C)	Study design considerations	Study type	Reference
			Feeding history: Starved Control: No		
Adult	Critical thermal maxima (endpoint was complete loss of equilibrium)	28–40.5	Sample size: 4 or 5 Acclimation temperature: 6.5–33.1°C (constant temperature within this range) Rate of change: 0.3°C per min. Feeding history: Satiated; fasted 24h before the trial Control: No	Laboratory	Woiwode and Adelman 1992
Adult	Critical thermal maxima (endpoint was complete loss of equilibrium)	34.6–39	Sample size: 4 or 5 Acclimation temperature: 20-28°C (constant temperature within this range) Rate of change: Diel oscillating temperatures (±4°C amplitude) Feeding history: Starved Control: No	Laboratory	Woiwode and Adelman 1992
Adult	Critical thermal maxima (endpoint was complete loss of equilibrium)	35.3–39.2	Sample size: 4 or 5 Acclimation temperature: 20–28°C (constant temperature within this range) Rate of change: Diel oscillating temperatures (±4°C amplitude) Feeding history: Satiated; fasted 24h before prior to the trial Control: No	Laboratory	Woiwode and Adelman 1992

In Situ, Model, or Other Publication Types

No in situ, model, or other publication types published in 1990 or later were found for this coolwater species.

Dissolved Oxygen

No DO data published in 1990 or later were found for this coolwater fish species.

Report Limitations

There are some limitations to our report that we would like to highlight for consideration. First, as stated above, some species included in the list of coolwater taxa may be considered warmwater or coldwater taxa elsewhere. Second, no relevant data were found for 14 of the taxa listed in Zaroban et al. (1999), yet these taxa may be biologically relevant or especially sensitive to their environment. Third, similarly to the taxa without relevant results were 40 taxa that lacked DO optima results of which 21 taxa also lacked thermal optima results. An increased research effort should focus on these taxa to more effectively understand the differences in DO and water temperature sensitivity among fishes in the

Pacific Northwest and improve environmental quality assessment and management. Finally, we would like to focus on the paucity of research that reports optimal or preferred DO concentrations. The majority of DO results reported negative physiological effects which do not help in deriving protective thresholds and LC50 results require considerable statistical manipulation to arrive at relevant results.

The data collected from this literature review might be considered in the future for Clean Water Act purposes such as in developing or evaluating water quality criteria to protect coolwater fish species. These results can also be used to inform and possibly identify the impact of pollution (e.g., extirpation of sensitive taxa) or evaluate the success of restoration projects (e.g., retention of sensitive taxa). In addition, coolwater fish thermal and DO tolerances will help forecast the potential impacts of climate change on the distribution of species and composition of aquatic communities in the Pacific Northwest.

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Appendix A: Example Boolean Search Logic

Original Boolean Search Logic

(("Catostomidae" OR "Catostomus ardens" OR “Utah sucker” OR "Catostomus columbianus" OR “Bridgelip sucker” OR "Catostomus discobolus" OR “Bluehead sucker” OR "Catostomus macrocheilas" OR “Largescale sucker” OR "Catostomus occidentalis" OR “Sacremento sucker” OR "Catostomus platyrhynchus" OR “Mountain sucker” OR "Catostomus rimiculus" OR “Klamath smallscale sucker” OR "Catostomus snyderi" OR “Klamath largescale sucker” OR "Catostomus tahoensis" OR “Tahoe sucker” OR "Catostomus warnerensis" OR “Warner sucker” OR "Chasmistes brevirostris" OR “Shortnose sucker” OR "Deltistes luxatus" OR “Lost River sucker” OR “Pumpkin seed” OR “*Lepomis gibbosus”* OR “*Micropterus dolomieu*” OR “Smallmouth bass” OR “Centrarchidae” OR “Clupeidae” OR “*Alosa sapidissima” OR “*American shad” OR “Cottidae” OR “*Cottus aleuticus” OR “*Coastrange sculpin” OR “*Cottus asper” OR “*Prickly sculpin” OR “*Cottus bairdii” OR “*Mottled sculpin” OR “*Cottus gulosus” OR “*Riffle sculpin*” OR “Cottus klamathensis“ OR “*Marbled sculpin” OR “*Cottus marginatus” OR “*Margined sculpin” OR “*Cottus perplexus” OR “*Reticulate sculpin” OR “*Cottus pitensis” OR “*Pit sculpin” OR “*Cottus tenuis” OR “*Slender sculpin” OR “Cyprinidae**”** OR “*Acrocheilus alutaceus” OR “*Chiselmouth” OR “*Gila atraria” OR “*Utah chub” OR “*Gila bicolor” OR “*Tui chub” OR “*Gila coerulea” OR “*Blue chub” OR “*Gila copei” OR “*Leatherside chub” OR “*Mylocheilus caurinus” OR “*Peamouth” OR “*Oregonichthys crameri” OR “*Oregon chub” OR “*Oregonichthys kalawatseti” OR “*Umpqua chub” OR “*Ptychocheilus oregonensis” OR “*Norther squawfish” OR “*Ptychocheilus umpquae” OR “*Umpqua squawfish” OR “*Rhinichthys cataractae” OR “*Longnose dace” OR “*Rhinichthys evermanni” OR “*Umpqua dace” OR “*Rhinichthys falcatus” OR “*Leopard dace” OR “*Rhinichthys osculus” OR “*speckled dace” OR “*Richardsonius balteatus” OR “*redside shiner” OR “*Richardsonius egregious” OR “*Lahontan shiner” OR “Esocidae” OR “*Esox americanus” OR “*grass pickerel” OR “*Esox Lucius” OR “*northern pike” OR “Gasterosteidae” OR “*Gasterosteus aculeatus” OR “*threespine stickleback” OR “Osmeridae” OR “*Spirinchus thaleichthys” OR “*longfin smelt” OR “*Thaleichthys pacificus” OR “*eulachon” OR “Percichthyidae” OR “*Monrone chrysops” OR “*white bass” OR “*Morone saxatilis” OR “*striped bass” OR “Percidae” OR “*Perca flavescens” OR “*yellow perch*” OR “Stizostedion vitreum” OR “*walleye” OR “Percopsidae” OR “*Percopsis transmontana” OR “*sand roller” OR “Petromyzontidae” OR “*Lampetra ayresi” OR “*river lamprey” OR “*Lampetra lethophaga” OR “*Pit-Klamath brook lamprey” OR “*Lampetra minima” OR “*Miller Lake lamprey*” OR “Lampetra richardsoni” OR “*western brook lamprey” OR “*Lampetra similis” OR “*Klamath River lamprey” OR “*Lampetra tridentate” OR “*Pacific lamprey” OR "coolwater fish" OR "coolwater species") AND ((“thermal tolerance” OR “lethal temperature” OR “Maximum Weekly Average Temperature” OR “Weekly Mean Temperature” OR “95% WMT” OR “Short-Term Maximum” OR “Critical Thermal Maximum” OR “Upper Lethal Temperature” OR “Upper Critical Range” OR “Upper Thermal Tolerance Limit” OR “Upper Incipient Lethal Temperature” OR “Ultimate Upper Incipient Lethal Temperature” OR “Upper Avoidance Temperature” OR “Final Temperature Preferendum” OR “Thermal stress” OR “thermal regime” OR “oxythermal” OR “thermal threshold” OR “thermal range” OR “thermal conditions” OR “thermal tolerance” OR “Thermal limits” OR “Thermal habitat”) OR (“Dissolved Oxygen” OR “DO tolerance”)))

Attachment #8: White Sturgeon Literature Review

Additional search logic for white sturgeon:

(“white sturgeon” OR “Acipenser transmontanus”) AND ((“thermal tolerance” OR “lethal temperature” OR “Maximum Weekly Average Temperature” OR “Weekly Mean Temperature” OR “95% WMT” OR “Short-Term Maximum” OR “Critical Thermal Maximum” OR “Upper Lethal Temperature” OR “Upper Critical Range” OR “Upper Thermal Tolerance Limit” OR “Upper Incipient Lethal Temperature” OR “Ultimate Upper Incipient Lethal Temperature” OR “Upper Avoidance Temperature” OR “Final Temperature Preferendum”) OR (“Dissolved Oxygen” OR “DO tolerance”))

Additional search logic for green sturgeon:

(“green sturgeon” OR “Acipenser medirostris”) AND ((“thermal tolerance” OR “lethal temperature” OR “Maximum Weekly Average Temperature” OR “Weekly Mean Temperature” OR “95% WMT” OR “Short-Term Maximum” OR “Critical Thermal Maximum” OR “Upper Lethal Temperature” OR “Upper Critical Range” OR “Upper Thermal Tolerance Limit” OR “Upper Incipient Lethal Temperature” OR “Ultimate Upper Incipient Lethal Temperature” OR “Upper Avoidance Temperature” OR “Final Temperature Preferendum”) OR (“Dissolved Oxygen” OR “DO tolerance”))