Summary of Temperature Metrics for Aquatic Invasive Fish Species in the Prairie Region

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Fish are poikilothermic meaning their internal body temperature reflects the temperature of their surrounding environment. For this reason, temperature is a strong predictor of species distribution and can be used to assess the likelihood that fish species can survive in newly invaded regions. In 2018, the Science and Research Branch of the Ontario Ministry of Natural Resources and Forestry compiled thermal metrics (e.g., critical thermal maximum and minimum, final temperature preferendum, and optimal spawning temperature) for numerous current and potential invasive species that could establish in the Laurentian Great Lakes region. The objective of this report was to apply a similar approach to explore the likelihood of establishment for non-native fishes that pose a risk to the Prairie region using thermal metrics. Based on a review of provincial and state agency webpages and discussion with local experts, 68 fish species were identified that either have invaded or are identified as potential invaders to the Canadian Prairie region. Thirty (44%) of the identified species are known to overwinter in the Prairie region. Therefore, the typical winter condition in the Prairie region is not a hindrance to the spread of these species throughout the region. From the thermal metrics, an additional nine species are thought to have the opportunity to establish in the Prairie region due to the ability to overwinter in the region. No temperature data were found for an additional ten species, though the majority of these species are unlikely to tolerate extreme winter conditions in the Prarie region. However, there was not sufficient data available for eleven species to assess their potential to survive winter conditions typical of the Prairie region. Given their current distribution range and habitat use, this is a knowledge gap that should be addressed to inform future risk assessments. Subsequently, several research opportunities have been identified to reduce knowledge gaps and inform risk assessments under current and warming climate regimes to predict the likelihood of species invasion and survival in the Prairie region.

RÉSUMÉ

Mackey, T., C.T. Hasler, and E.C. Enders. 2019. Summary of Temperature Metrics for Aquatic Invasive Fish Species in the Prairie Region. Can. Tech. Rep. Fish. Aquat. Sci. 3308: viii + 62 p.

Les poissons sont poikilothermiques, ce qui signifie que leur température interne du corps reflète la température de leur environnement. Pour cette raison, la température est un puissant facteur de prédiction de la distributtion des espèces et peut être utilisée pour évaluer la probabilité de survie des espèces de poissons dans les régions nouvellement envahies. En 2018, la Direction de la science et de la recherche du ministère des Richesses naturelles et des Forêts de l'Ontario a compilé des mesures thermiques (e.g., maximum et minimum thermiques critiques, température préférentielle finale, température de frai optimale) pour de nombreuses espèces envahissantes actuelles et potentielles pouvant s'établir dans la région des Grands Lacs Laurentiens. L'objectif de ce rapport était d'appliquer une approche similaire afin d'explorer la probabilité d'établissement des poissons non indigènes présentant un risque pour la région des Prairies à l'aide de mesures thermiques. Après un examen des pages web des organismes provinciaux et d'États américains et des discussions avec des experts locaux, 68 espèces de poissons envahissantes ou potentiellement envahissantes pour la région des Prairies canadiennes ont été identifiées. On sait que trente (44%) des espèces identifiées hivernent déjà dans les Prairies. Par conséquent, les conditions hivernales typiques dans la région des Prairies ne constituent pas un obstacle à la propagation de ces espèces dans la région. D'après les mesures thermiques, neuf espèces supplémentaires auraient la possibilité de s'établir dans les Prairies en raison de leur capacité à hiverner dans la région. Aucune donnée de température n'a été trouvée pour dix espèces supplémentaires, bien que la majorité de ces espèces ne tolèrent probablement pas les conditions hivernales extrêmes de la région de Prairie. Cependant, il n'y avait pas suffisamment de données disponibles sur onze espèces pour évaluer leur potentiel de survie aux conditions hivernales typiques de la région des Prairies. Compte tenu de leur aire de répartition actuelle et de leur utilisation de l'habitat, il s'agit de combler le manque de connaissances pour éclairer les futures évaluations des risques. Par la suite, plusieurs possibilités de recherche ont été identifiées afin de réduire les lacunes dans les connaissances et d'éclairer les évaluations des risques sous les régimes climatiques actuels et en réchauffement afin de prédire la probabilité d'invasion et de survie des espèces dans la région des Prairies.

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INTRODUCTION

Fish are poikilothermic, meaning their internal body temperature reflects that of their surrounding environment. Temperature is considered the master abiotic factor, driving most life processes from growth, reproduction, fish movement and ultimately, the fitness and survival of a species via its temperature optima (Fry 1971; Beitinger et al. 2000). As a result, the distribution of most fishes is largely dictated by local temperature conditions (Beitinger and Magnuson 1975). As climate conditions continue to change, local temperature extremes may become more favourable or unfavourable for fishes and, thus, affect the likelihood that fish will thrive (i.e., grow, reproduce, and survive) in a particular environment (Lynch et al. 2016). Beyond considerations for native fish conservation, changing thermal conditions may potentially result in the successful establishment of non-native fishes as local environments warm to meet their specific thermal tolerances. Therefore, it is important to assess changing thermal conditions and the risk to native fish communities should new non-native fishes be introduced to local waterbodies.

Non-native fishes refer to any species that is not indigenous to a given waterbody. It is common practice among scientists, resource managers, and policy writers to refer to non-native fishes that have negative effects on the native biota as invasive, although this is not necessarily true for all fishes deemed 'invasive' (Ricciardi and Cohen 2007). Whether a fish is considered invasive is not limited to the origin of the species. For example, Prussian Carp are native to Eurasia and have invaded waterbodies in southeastern Alberta (Docherty et al. 2017) while Smallmouth Bass *Micropterus dolomieu*, which are native to Canada, have been deemed invasive to Canadian 'trout lakes' (Sharma et al. 2009). The degree to which a non-native species is considered a risk to local biota is based on the species' ability to thrive and its ability to withstand regional environmental conditions. Generalists are thought to be able to (1) thrive in a greater range of environmental/habitat conditions by growing faster, reproducing earlier, etc. than native species, or (2) may be better equipped to the new thermal regimes. In Canada, cold temperatures and hypoxia are common occurrences throughout the winter and can pose as barriers to the establishment of non-native fishes. However, some waterbodies are expected to experience shorter and warmer winters resulting from climate change, which should increase the likelihood that non-native fishes can establish in northern waterbodies (Rahel and Olden 2008).

In 2018, the Science and Research Branch of the Ontario Ministry of Natural Resources and Forestry (OMNRF) compiled nine thermal metrics including critical thermal maximum and minimum, final temperature preferendum, optimal spawning temperature for 73 current and potential invasive species that could establish in the Laurentian Great Lakes region (Hatton et al. 2018). The authors concluded that a complete set of thermal metrics was not available for all identified non-native fish of concern. This paucity of data highlights the need for further research to study thermal metrics and inform risk analysis for establishment of non-native species in Ontario and the Great Lakes region (Hatton 2018).

The aim of the present report is to document thermal metrics for non-native species of concern in the Canadian Prairie region including Manitoba, Saskatechwan, and Alberta. The thermal metrics chosen for the analysis are based on Hasnain et al. (2013) who documented thermal metrics for indigenous freshwater fishes of Canada. The applied thermal metrics are important for biological processes related to survival, growth, and reproduction, which all affect population growth. A limiting factor for species on their northern range distribution is overwinter survival, consequently, thermal metrics defining lower temperature tolerance were also summarized. This dataset will be informative for future risk assessments by providing a better knowledge of temperature ranges where non-native fishes may establish.

The objectives of this report are to (1) summarise thermal metrics for non-native fishes that pose a risk of establishment in the Prairie region and to (2) highlight data and knowledge gaps to identify future research needs and to inform risk analysis of the likelihood of establishment based on thermal metrics for non-native fishes in the Prairie region.

METHODOLOGY

Data collection

The Prairie region was defined as the inland waters of Manitoba, Saskatchewan, and Alberta. Consequently the search for potential non-native fish to the Prairie region was limited to non-native fishes in the adjacent provinces (British Columbia and Ontario) and states (Washington, Idaho, Montana, North Dakota, and Minnesota). Fishes found in each of the Prairie provinces that are known to 'invade' waterbodies that they are not commonly found in were included in this report. In brief, our list of potential invaders was derived from searching provincial and state agency webpages that discuss fishes of concern.

In brief, the list of potential invaders was derived by searching relevant provincial and state agency webpages for non-native fish species that are of concern for the corresponding jurisdiction. Provincial and state aquatic invasive species (AIS) legislations for prohibited species lists were also consulted. In addition, local AIS fish experts (e.g., provincial and federal AIS biologists) were contacted to ensure that the list was comprehensive and applicable to the Prairie region.

For each fish identified, species-specific data was obtained from Hatton et al. (2018), when there was overlap between species with the Great Lakes, or gathered from primary and secondary literature, technical reports. These were identified using online search tools (i.e., Google Scholar, Google Search Engine, and ISI Web of Science) using relevant species name (common and scientific names) and keywords associated with each of the thermal metrics (Table 1). Once data gaps in the thermal metrics were identified, a network of experts was contacted to inquire about data to fill the data gaps. Information provided by webpages that could not be verified was not included in the report. Given the overlap in species between the Great Lakes region and the Prairie region, much of the data was available from Hatton et al. (2018) and the references provided within the report.

Metrics

The nine thermal metrics used in this report are based on the work by Hasnain et al. (2013) and Hatton et al. (2018) (Table 1). These metrics are upper and lower incipient lethal temperature (UILT (Table A1) and LILT (Table A4), respectively), critical thermal maximum and minimum (CT_{max} (Table A1) and CT_{min} (Table A4), respectively), and lower thermal tolerance (LTT; Table A5) to determine survival, optimal growth temperature (OGT and final temperature preferendum (FTP) for growth (Table A2), optimal spawning (OS) and optimal egg development (OE) temperature for reproduction (Table A3). When evaluating the potential limits of survival, growth, and reproductive aspects of each species at least two metrics were used.

Assumptions that fish could survive winter were also made based on the definitions provided by Hatton et al. (2018). A fish species was assumed to 'likely' be able to overwinter in the Prairie region if it had either demonstrated the ability to overwinter based on laboratory survival at temperatures < 8 °C , had been observed overwintering in a climate similar to the Prairie region or directly observed to overwinter in the Prairie region like for example Smallmouth Bass *Micropterus dolomieu*. A 8 °C threshold was chosen because despite the fact that maximum water column temperature in the winter is expected to be 4 °C (Wetzel 1975), industrial or urban water outlets such as wastewater treatment facilities and urban runoff may produce elevated thermal refuges for overwintering fish. Consequently, to not be overly conservative on the estimation of the thermal limits, a lower threshold of 8 °C was used for the winter survival temperature threshold.

Table 1. Definitions of the thermal metrics used to describe temperatures for fish survival, growth, and reproduction (adapted from Hatton et al. 2018).

Biological category	Thermal metric	Description
Survival	**UILT / LILT** upper or lower incipient lethal temperature	Temperature below (upper) / above (lower) which > 50% of fish will survive experimental conditions
	CT_{max} / CT_{min} critical thermal maximum or minimum	Temperature above (maximum) or below (minimum) which fish loses its ability to maintain upright posture in the water column in experimental conditions
Growth	**LTT** lower temperature tolerance	Lowest tolerated or observed temperature from field or laboratory studies
	OGT optimal temperature tolerance	Temperature that supports the highest individual growth rate in the absence of confounding factors
	FTP final temperature preferendum	Temperature selected by the species when exposed to a wide range of temperatures
Reproduction	**OS** optimal spawning temperature	Temperature most frequently associated with spawning
	OE optimal egg development	Temperature at which rate of egg development is optimised

A fish species was assumed to 'possibly' be able to overwinter in the Prairie region if it had LILT, CT_{min}, or LTT < 8 ºC based on acute exposure studies rather than overwintering observations. A fish species was assumed to 'unlikely' have the ability to overwinter in the Prairie region if LILT, CT_{min}, or LTT > 8 ºC or if the known range was subtropical or tropical. Fish species that lacked laboratory or observational data were classified as 'insufficient data'.

For the reproductive guild, species were grouped based on reproductive behaviour (adapted from Coker et al. 2001) and classified in six categories of spawning behaviour (Table A6):

A1 = non-guarder, broadcast spawner
A2 = non-guarder, brood hider
B1 = guarder, substrate chooser
B2 = guarder, nest spawner
C1 = external bearer
C2 = internal bearer

Data management and statistical analysis

All fish species were categorised by family, thermal and reproductive guilds, and the geographic origin (continent) based on information provided by FishBase (Froese and Pauley 2018). Thermal guilds followed the classification by Coker et al. (2001), i.e., warm water fish = final temperature preferendum (FTP) >25 °C, cool water fish = FTP 19–25 °C, and cold water fish = FTP <19 °C. The maximum value for each thermal metric was used when multiple temperature values were identified from literature.

The different thermal metrics are presented in box and whisker plots where the middle line presents the median, the box presents the upper quartile (25% of the data is greater than this value) amd lower (25% of the data is less than this values), and the whiskers present the maximum value and minimum values excluding any outliers, amd the dots an outliers that more or less than 1.5-times the interquartile range. All data and statistical analyses were conducted in R (R Core Development Team 2018)

RESULTS

Based on the review of provincial and state agency webpages and discussions with local experts, the following 68 species were of concern as potential invaders to the Prairie region, as they are known to certain areas in the Prairie region and/or have invasive tendencies where they have been introduced (Table 2). It was denoted which of the fish species were also reported as being of concern for the Great Lakes region by Hatton et al. (2018), which species are native to certain areas in the Prairie region (N) or have been introduced to at least one waterbody in the Prairie region (IP).

For 34% of the fish species, seven to eight thermal metrics were available, 33% had either five to six metrics, and 18% had one to five metrics (Tables 2 and 3). However, no temperature data were found for the following ten species (15%): Alligator Gar, Black Piranha, Bullseye Snakehead, Giant Snakehead, Large-spot Catfish, Midas Chichlid, Ohrid Trout, Oscar, Red-bellied Piranha, and Redtail Catfish. With the exceptions of Ohrid Trout (endemic to the Balkans) and Alligator Gar (found in the Upper Midwest USA) (S. David, Nicholls State University, pers. comm.), none of these ten species are likely to endure prolonged temperatures < 8 °C due to their tropical and sub-tropical origin and consequently are unlikely to survive the harsh and long winter conditions in the Prairie region.

Assumption of winter survival or identification of existing knowledge gaps could be provided for all 68 fish species from the known distribution extent and/or thermal data (Table A5). Thirty (44%) of the identified species are known to overwinter in the Prairie region and, therefore, the winter conditions in the Prairie region seem to not hinder the spread of these species within the different areas of the Prairie region. Other environmental, biological, or physical factors should be reviewed for these species to predict their survival, growth, and reproduction in local inland waters.

Table 2. List of 68 fish species that are of concern for the Prarie region as potential invaders. Species and common name are provided and an indication if species have also been reported of concern for the Great Lakes (GLR) region by Hatton et al. (2018), if species are native to certain areas in the Prairie region (N) or have been introduced to at least one waterbody in the Prairie region (IP).

Species name	Common name	Category
Acipenser medirostris	Green Sturgeon	
Alosa pseudoharengus	Alewife	GLR
Amia calva	Bowfin	
Ameiurus melas	Black Bullhead	N, IP
Ameiursus natalis	Yellow Bullhead	IP
Ameiurus nebulosus	Brown Bullhead	IP
Amphilophus citrinellus	Midas Cichlid	
Astronotus ocellatus	Oscar	
Atractosteus spatula	Alligator Gar	
Carassius auratus	Goldfish	IP
Carassius gibelio	Prussian Carp	GLR, IP
Channa argus	Northern Snakehead	GLR
Channa maculata	Blotched Snakehead	GLR
Channa marulius	Bullseye Snakehead	
Channa micropeltes	Giant Snakehead	
Ctenopharyngodon idella	Grass Carp	GLR
Cyprinella lutrensis	Red Shiner	GLR
Cyprinus carpio	Common Carp	GLR, IP
Esox lucius	Northern Pike	N, IP
Esox masquinongy	Muskellunge	IP
Gambusia affinis	Western Mosquitofish	GLR
Gymnocephalus cernuus	Eurasian Ruffe	GLR
Hemichromis letourneuxi	African Jewelfish	IP
Hypophthalmichthys molitrix	Silver Carp	GLR
Hypophthalmichthys nobilis	Bighead Carp	GLR
Ictalurus punctatus	Channel Catfish	N, IP
Ictiobus cyprinellus	Bigmouth Buffalo	N, IP
Lepomis cyanellus	Green Sunfish	
Lepomis gibbosus	Pumpkinseed	N
Lepomis macrochirus	Bluegill	N, IP
Leuciscus idus	Orfe or Ide	GLR
Micropterus dolomieu	Smallmouth Bass	IP
Micropterus salmoides	Largemouth Bass	IP
Misgurnus anguillicaudatus	Japanese Weatherfish	GLR
Morone americana	White Perch	GLR
Morone chrysops	White Bass	IP
Mylopharyngodon piceus	Black Carp	GLR
Neogobius melanostomus	Round Goby	GLR

Species name	**Common name**	**Category**
Notropis hudsonius	Spottail Shiner	N, IP
Noturus gyrinus	Tadpole Madtom	N, IP
Oncorhynchus aguabonita	Golden Trout	IP
Oncorhyncus mykiss	Rainbow Trout	IP
Oreochromis niloticus	Nile Tilapia	GLR
Osmerus mordax	Rainbow Smelt	GLR, IP
Perca flavescens	Yellow Perch	N, IP
Percopsis omiscomaycus	Trout Perch	IP
Petromyzon marinus	Sea Lamprey	GLR
Phractocephalus hemiollopterus	Redtail Catfish	
Pimephales promelas	Fathead Minnow	N
Platygobio gracilis	Flathead Chub	N, IP
Poecilia latipinna	Sailfin Molly	IP
Pomoxis annularis	White Crappie	N, IP
Pomoxis nigromaculatus	Black Crappie	IP
Proterorhinus semilunaris	Tubenose Goby	GLR
Pseudorasbora parva	Stone Moroko	GLR
Pygocentrus nattereri	Red-bellied Piranha	
Rhodeus amarus	Amur Bitterling	GLR
Salmo letnica	Ohrid Trout	
Salmo trutta	Brown Trout	IP
Salvelinus fontinalis	Brook Trout	N, IP
Sander lucioperca	Zander	GLR
Sander vitreus	Walleye	N, IP
Scardinius erythrophthalmus	Rudd	GLR
Serrasalmus rhombeus	Black Piranha or Redeye Piranha	
Silurus glanis	Wels Catfish	GLR
Synodontis ocellifer	Large-spot Catfish	
Tinca tinca	Tench	GLR
Umbra limi	Central Mudminnow	N, IP

African Jewelfish, Blotched Snakehead, Green Sturgeon, and Wels Catfish were deemed unlikely to have overwintering ability based on thermal metrics. Nile Tilapia, Northern Snakehead, and Sailfin Molly may have the ability to overwinter in the Prairie region based on CT_{min} and LILT values < 8 °C. However, species- specific responses to chronic exposure to cold conditions are not currently known. Based on the thermal criteria for overwintering and known species distributions,

- Alewife
- Grass Carp
- Orfe (or Ide)
- Round Goby
- Rudd
- Stone Moroko
- Tench
- Tubernose Goby
- Zander

will likely survive winter conditions in the Prairie region (see Table 3 for details).

Insufficient data was available to assess the likelihood that the following fish could survive winter conditions typical of the Prairie region (Table 3), and given their current distributions and habitat needs, should be considered as significant knowledge gaps:

- Amur Bitterling
- Alligator Gar
- Bighead Carp
- Black Carp
- Eurasian Ruffe
- Golden Trout
- Green Sunfish
- Ohrid Trout
- Red Shiner
- Silver Carp
- White Perch.

Table 2. Six thermal metrics (upper incipient lethal temperature [UILT], critical thermal maximum [CT_{max}], optimal growth temperature [OGT], final temperature preferendum [FTP], optimal spawning temperature [OS], and optimal temperature for egg development [OE]) for identified species (see Appendix for references). Ranges reported in the literature.

Family	Scientific name	Common name	Temperature (ºC)					
			UILT	CT_{max}	OGT	FTP	OS	OE
Acipenseridae	*Acipenser medirostris*	Green Sturgeon	17	34	11–20.8	15–16	8–14	15
Ammidae	*Amia calva*	Bowfin	-	37	-	30.3–30.5	16–19	-
Catostomidae	*Ictiobus cyprinellus*	Bigmouth Buffalo	-	-	-	6–26	15.5–18.3	20.5
Centrarchidae	*Lepomis cyanellus*	Green Sunfish	40	34.2–37.9	28	15.9–30.6	16.7–21.9	29.1
	Lepomis gibbosus	Pumpkinseed	24.5–37	30.1–37.5	25	22.9–31.7	24–30	28
	Lepomis macrochirus	Bluegill	31–34	38.3–41.5	24–31	27.4–32	25	22–24
	Micropterus dolomieu	Smallmouth Bass	35–37	36.3	25–27	12–31.3	18	21
	Micropterus salmoides	Largemouth Bass	28.9–36.4	33.6–41.8	18–25	27–32	15.6–21	20
	Pomoxis annularis	White Crappie	33	32.8	25–28.5	10.4–24	14–20	-
	Pomoxis nigromaculatus	Black Crappie	32.5–34	34.9	22–25	20–24.6	17.8–20	16–20
Channidae	*Channa argus*	Northern Snakehead	35	38	23–30.3	14–33	18–29	25–31
	Channa maculata	Blotched Snakehead	38	41	27	20–35	25–28	-
	Channa marulius	Bullseye Snakehead	-	-	-	-	-	-
	Channa micropeltes	Giant Snakehead	-	-	-	-	-	-
Cichlidae	*Amphilophus citrinellus*	Midas Cichlid	-	-	-	-	-	-
	Astronotus ocellatus	Oscar	-	-	-	-	-	-
	Hemichromis letourneuxi	African Jewelfish	-	-	-	-	-	-
	Oreochromis niloticus	Nile Tilapia	37–42	40–42	20–30	13.5–36	21–28	27
Clupeidae	*Alosa pseudoharengus*	Alewife	23–34	30.2–34	20.1	11–28.3	12.9–27.7	17.7–20.8

Family	Scientific name	Common name	Temperature (□C)					
			UILT	**CT_{max}**	**OGT**	**FTP**	**OS**	**OE**
Cobitidae	*Misgurnus anguillicaudatus*	Japanese Weatherfish	30	38	20–30	5–25	20	23–30
Cyprinidae	*Carassius auratus*	Goldfish	29–41	34.5–39.6	25–28.1	25.4–29	17–24	18.5–29.5
	Carassius gibelio	Prussian Carp	-	-	-	0.5–41	13.5–29.4	20.5
	Ctenopharyngodon idella	Grass Carp	34–39	39.3	18.3–30	25.3–29	22–30	22–32
	Cyprinella lutrensis	Red Shiner	34–39	35.9–39.7	-	30	30–34	24.5
	Cyprinus carpio	Common Carp	31–41.9	38–41	20–32	29–32	15–23	16–23
	Hypophthalmichthys molitrix	Silver Carp	43–46.3	-	24–34	27.1–29	14–28	22.3–26
	Hypophthalmichthys nobilis	Bighead Carp	38	38.8	25–30	25.4–27	18–30	22–30
	Leuciscus idus	Orfe or Ide	24–37.9	-	-	4–35	4–15	9.5–23
	Mylopharyngodon piceus	Black Carp	40	-	24–32	-	18–36	21–28
	Notropis hudsonius	Spottail Shiner	30.6–31.1	32.8	27.3	14–20	18–20	20
	Pimephales promelas	Fathead Minnow	28.2–33.2	28.6–40.4	25.5–26	28.5–29	23.5	25
	Platygobio gracilis	Flathead Chub	-	-	-	-	-	-
	Pseudorasbora parva	Stone Moroko	-	-	-	5–22	15–19	20
	Rhodeus sericeus	Amur Bitterling	35.7–36.5	-	12–29.9	14–25	12–24	-
	Scardinius erythrophthalmus	Rudd	35–36.5	29–38	14–28	2–35	14–20	17.5–24
	Tinca tinca	Tench	32.3–39.3	37	12–30	4–38	18–26	19–25.5
Esocidae	*Umbra limi*	Central Mudminnow	33.5–38	-	-	-	12.8–13	-
	Esox lucius	Northern Pike	29.4–33	33.3	19–26	19–20	10	6.4–20.8
	Esox masquinongy	Muskellunge	29–34	32	24–26.6	14–27.3	12.8–18	13.5
Gobiidae	*Neogobius melanostomus*	Round Goby	25.7–33.4	31.5–33.4	-	24.6	9–26	19–21
	Proterorhinus semilunaris	Tubernose Goby	31.9	-	-	11–23	-	-
Ictaluridae	*Ameiurus melas*	Black Bullhead	35	37.5–38.1	-	-	21	-
	Ameiurus natalis	Yellow Bullhead	-	36.4–37.9	-	27.6–28.8	-	-
	Ameiurus nebulosus	Brown Bullhead	28.6–37.5	38	28.2–32	11.9–31	21.1	-
	Ictalurus punctatus	Channel Catfish	28.6–37.5	34.5–42.1	28–30	23–32.5	23.9–26.7	22
	Noturus gyrinus	Tadpole Madtom	-	38	-	-	-	-
Lepisosteidae	*Atractosteus spatula*	Alligator Gar	-	-	-	-	-	-
Mochokidae	*Synodontis ocellifer*	Large Spot Catfish	-	-	-	-	-	-
Moronidae	*Morone americana*	White Perch	33–36	34–35.5	24–28.5	26–32.5	10–20	15–20.9
	Morone chrysops	White Bass	30–36.1	35.3	16–24	12–34	14.7–16.3	16–23.9
Osmeridae	*Osmerus mordax*	Rainbow Smelt	18–21	18–28.5	-	6–16	4.5–18.3	11–22.5
Percidae	*Gymnocephalus cernuus*	Eurasian Ruffe	28–35	30–34.5	18–30	19	6–20.2	9–21
	Perca flavescens	Yellow Perch	21–31.3	35	22.5–30	7–27	5–12	10–20
	Sander lucioperca	Zander	30–36	33–35.3	10–30	6–29	8–22	12–23
	Sander vitreus	Walleye	31–33	23.4	19–26	20–23.2	3.4–10	6–19.4

Family	Scientific name	Common name	Temperature (°C)					
			UILT	CT_{max}	OGT	FTP	OS	OE
Percopsidae	*Percopsis omiscomaycus*	Trout Perch	-	22.9	-	7–18	15–20	-
Petromyzontidae	*Petromyzon marinus*	Sea Lamprey	24–31	-	15–21	5–22	14–26.1	11–23
Pimelodidae	*Phractocephalus hemioliopterus*	Redtail Catfish	-	-	-	-	-	-
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	36–40	36–43	28.6–	28–35.1	5–23	19–20
	Poecilia latipinna	Sailfin Molly	-	38.7–41.8	-	-	-	-
Salmonidae	*Oncorhynchus aguabonita*	Golden Trout	-	27.7–30.3	-	-	-	-
	Oncorhynchus mykiss	Rainbow Trout	22.6–27	28.2–29.9	12–17	11.3–22	6–8	7–10
	Salmo letnica	Ohrid Trout	-	29–29.9	-	-	-	-
	Salmo trutta	Brown Trout	23–26.4	25–26	10–15.5	13.8–23.9	6.7–8.9	7.5
	Salvelinus fontinalis	Brook Trout	24–25.8	28.7–29.9	13–16.1	14.8–20.3	10.7	6
Serrasalmidae	*Pygocentrus nattereri*	Red-bellied Piranha	-	-	-	-	-	-
	Serrasalmus rhombeus	Black/Redeye Piranha	-	-	-	-	-	-
Siluridae	*Siluris glanis*	Wels Catfish	33	-	12–28	4–31	18–25	20–28

Table 3. Thermal metrics, i.e., lower incipient lethal temperature (LILT), critical thermal minimum (CT_{min}), and lower lethal temperature (LLT) for 68 identified species of concern as potential invaders to the Prairie region. Winter survival assumption was determined based on known distribution of the species and available thermal metrics. Ranges reported in the literature.

Family	**Scientific name**	**Common name**	**Temperature (°C)**			**Winter survival assumption**
			LILT	**CT_{min}**	**LLT**	
Acipenseridae	*Acipenser medirostris*	Green Sturgeon	-	-	-	unlikely
Ammidae	*Amia calva*	Bowfin	-	-	-	insufficient data
Catostomidae	*Ictiobus cyprinellus*	Bigmouth Buffalo	-	-	-	known overwinter in region
Centrarchidae	*Lepomis cyanellus*	Green Sunfish	-	-	-	insufficient data
	Lepomis gibbosus	Pumpkinseed	1.1–8.5	1.7–12.1	-	known overwinter in region
	Lepomis macrochirus	Bluegill	3–11	-	-	known overwinter in region
	Micropterus dolomieu	Smallmouth Bass	2–10	-	-	known overwinter in region
	Micropterus salmoides	Largemouth Bass	5.2–11.8	3.2	-	known overwinter in region
	Pomoxis annularis	White Crappie	-	-	-	known overwinter in region
	Pomoxis nigromaculatus	Black Crappie	-	-	-	known overwinter in region
Channidae	*Channa argus*	Northern Snakehead	-	0	5	possibly
	Channa maculata	Blotched Snakehead	-	-	-	unlikely
	Channa marulius	Bullseye Snakehead	-	-	-	unlikely (range)
	Channa micropeltes	Giant Snakehead	-	-	-	unlikely (range)
Cichlidae	*Amphilophus citrinellus*	Midas Cichlid	-	-	-	unlikely (range)
	Astronotus ocellatus	Oscar	-	-	-	unlikely (range)
	Hemichromis letourneuxi	African Jewelfish	9.1–13.3	10.8–12.5	-	unlikely
	Oreochromis niloticus	Nile Tilapia	5–13.3	-	-	possibly
Clupeidae	*Alosa pseudoharengus*	Alewife	0	-	-	likely
Cobitidae	*Misgurnus anguillicaudatus*	Japanese Weatherfish	-	- 1.8	-	possibly
Cyprinidae	*Carassius auratus*	Goldfish	-	0.3–1.3	-	known overwinter in region
	Carassius gibelio	Prussian Carp	-	0.5	-	known overwinter in region
	Ctenopharyngodon idella	Grass Carp	-	0.5	-	likely
	Cyprinella lutrensis	Red Shiner	-	-	-	insufficient data
	Cyprinus carpio	Common Carp	-	3	-	known overwinter in region
	Hypophthalmichthys molitrix	Silver Carp	-	-	-	insufficient data
	Hypophthalmichthys nobilis	Bighead Carp	-	-	2	insufficient data
	Leuciscus idus	Orfe or Ide	-	4	-	likely
	Mylopharyngodon piceus	Black Carp	-	-	0.5	insufficient data
	Notropis hudsonius	Spottail Shiner	-	-	-	known overwinter in region
	Pimephales promelas	Fathead Minnow	-	5.9	-	known overwinter in region
	Platygobio gracilis	Flathead Chub	-	-	-	known overwinter in region
	Pseudorasbora parva	Stone Moroko	-	5	2	likely
	Scardinius erythrophthalmus	Rudd	-	2	-	likely

Family	Scientific name	Common name	Temperature (°C)			Winter survival assumption
			LILT	CT_{min}	LLT	
	Tinca tinca	Tench	-	4	-	likely
Esocidae	*Umbra limi*	Central Mudminnow	-	-	-	known overwinter in region
	Esox lucius	Northern Pike	0.1	-	-	known overwinter in region
	Esox masquinongy	Muskellunge	-	-	-	known overwinter in region
Gobiidae	*Neogobius melanostomus*	Round Goby	-1	4	-	likely
	Proterorhinus semilunaris	Tubernose Goby	-	4	-	likely
Ictaluridae	*Ameiurus melas*	Black Bullhead	-	-	-	known overwinter in region
	Ameiurus natalis	Yellow Bullhead	-	-	-	known overwinter in region
	Ameiurus nebulosus	Brown Bullhead	-	-	-	known overwinter in region
	Ictalurus punctatus	Channel Catfish	0–6	2.7–9.8	-	known overwinter in region
	Noturus gyrinus	Tadpole Madtom	-	-	-	known overwinter in region
Lepisosteidae	*Atractosteus spatula*	Alligator Gar	-	-	-	insufficient data
Mochokidae	*Synodontis ocellifer*	Large-spot Catfish	-	-	-	unlikely (range)
Moronidae	*Morone americana*	White Perch	-	-	-	insufficient data
	Morone chrysops	White Bass	-	-	-	known overwinter in region
Osmeridae	*Osmerus mordax*	Rainbow Smelt	-	-	-	known overwinter in region
Percidae	*Gymnocephalus cernuus*	Eurasian Ruffe	-	-	-	insufficient data
	Perca flavescens	Yellow Perch	1.1–3.7	-	-	known overwinter in region
	Sander lucioperca	Zander	-0.6	-	-	likely
	Sander vitreus	Walleye	2–7	-	-	known overwinter in region
Percopsidae	*Percopsis omiscomaycus*	Trout Perch	-	-	-	known overwinter in region
Petromyzontidae	*Petromyzon marinus*	Sea Lamprey	-	-	0	likely
Pimelodidae	*Phractocephalus hemioliopterus*	Redtail Catfish	-	-	-	unlikely (range)
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	2.7–3	3	-	known overwinter in region
	Poecilia latipinna	Sailfin Molly	-	2.1–8.6	-	possibly
Salmonidae	*Oncorhynchus aguabonita*	Golden Trout	-	-	-	insufficient data
	Oncorhynchus mykiss	Rainbow Trout	0.5–3.3	0–2.1	-	known overwinter in region
	Salmo letnica	Ohrid Trout	-	-	-	insufficient data
	Salmo trutta	Brown Trout	-	-	-	known overwinter in region
	Salvelinus fontinalis	Brook Trout	-	-	-	known overwinter in region
Serrasalmidae	*Pygocentrus nattereri*	Red-bellied Piranha	-	-	-	unlikely (range)
	Serrasalmus rhombeus	Black/Redeye Piranha	-	-	-	unlikely (range)
Siluridae	*Siluris glanis*	Wels Catfish	13–14	-	-	unlikely

Cyprinids had the highest and widest distribution of upper temperature metrics including UILT, OGT, FTP, and OS (Figure 1). Cyprinids are distributed throughout temperate regions and, therefore, are frequently exposed to warm and cool water conditions. In contrast, salmonids had the lowest and narrowest upper temperature metrics, in many cases over 10 °C below other families (Figure 1). Salmonid species are typically considered to be cool- and cold-tolerant fish species. Relatively, few data points were available to analyse taxonomic trends in lower temperature metrics, though cyprinids and percids were found to have lower temperatures than centrarchids (Figure 2) due to cyprinids' distribution in more northern climates than centrarchids, which are primarily warm-water species.

Fish of North American origin had a wider range of upper temperature metrics while Asian and African species had narrower ranges and higher values for all upper thermal metrics in comparison to Eurasian and North American fish species (Figure 3). These trends are explained by the taxonomic families that have evolved in these regions as several tropical fishes were considered to originate from Africa and Asia and these species are unlikely to be found in the other regions. Relatively few data points were available for assessing the influence of origin on lower thermal metrics. However, fish from North America have LILT and CT_{min} values ranging between 0 and 12 °C (Figure 4). LILT < 0 °C relates to species occurring in brackish water.

Temperature guilds followed expectations with upper temperature metrics increasing as guilds became more warm-water tolerant, i.e., cold and cool guilds had lower upper temperature metrics in comparison to species from warm and warm/cool temperature guilds (Figure 5). Interestingly, species classified as cool/cold had the lowest median values with respect to UILT, OGT, FTP, OS, and OE, likely reflecting the many salmonid species found in the cool/cold temperature guild. Again, relatively few data points were available for assessing the influence of temperature guilds on lower thermal metrics. However, it was clear that species from lower water temperature guilds tended to have a wide distribution of lower limits with some even reaching 0 °C (Figure 6).

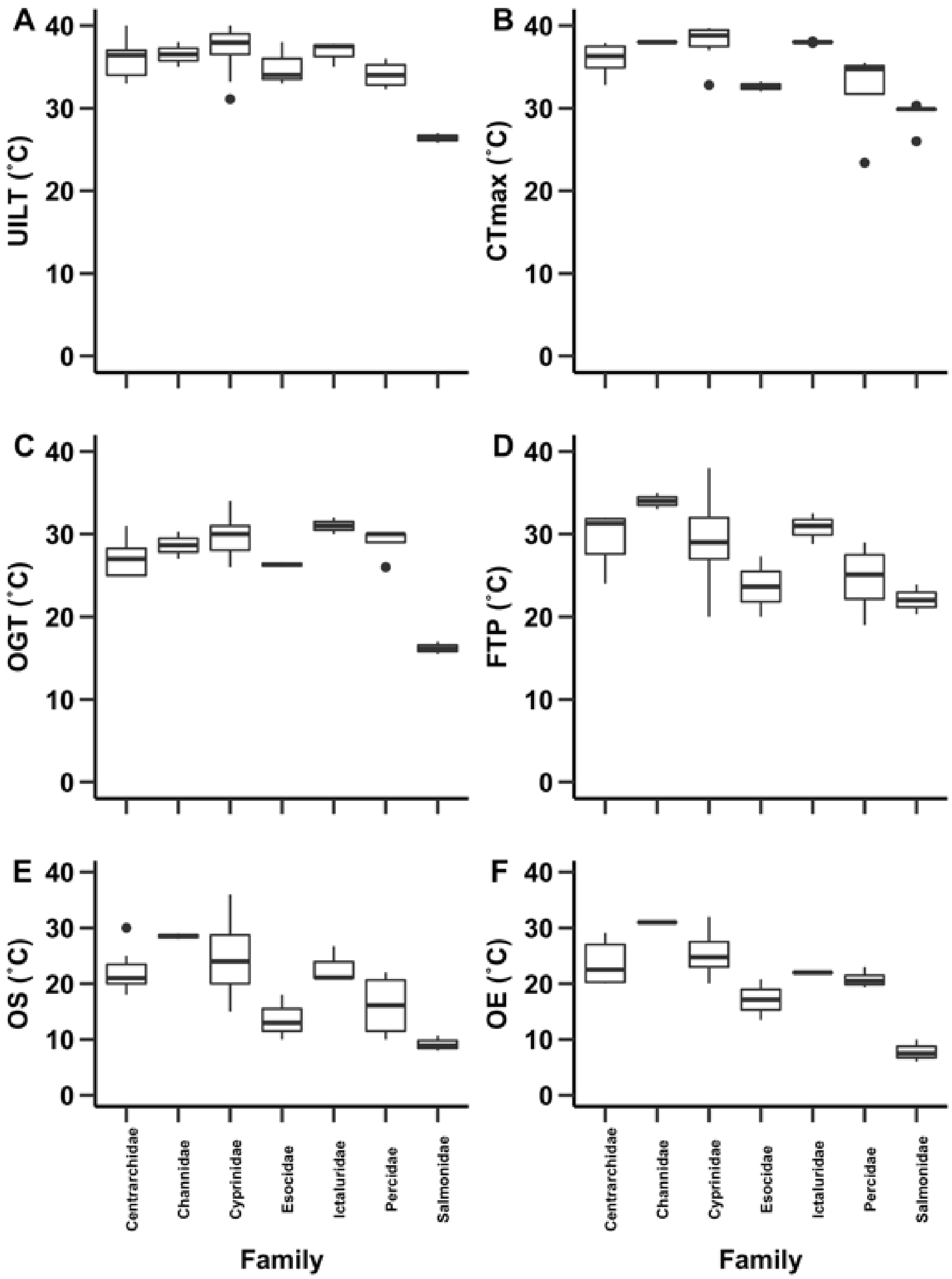

Figure 1. Distribution of six thermal metrics for species identified as potentially invasive to the Prairie region grouped by family. (A) upper incipient lethal temperature (UILT), (B) critical thermal maximum (CT_{max}), (C) optimal growth temperature (OGT), (D) final temperature preferendum (FTP), (E) optimal spawning temperature (OS), and (F) optimal egg development temperature (OE).

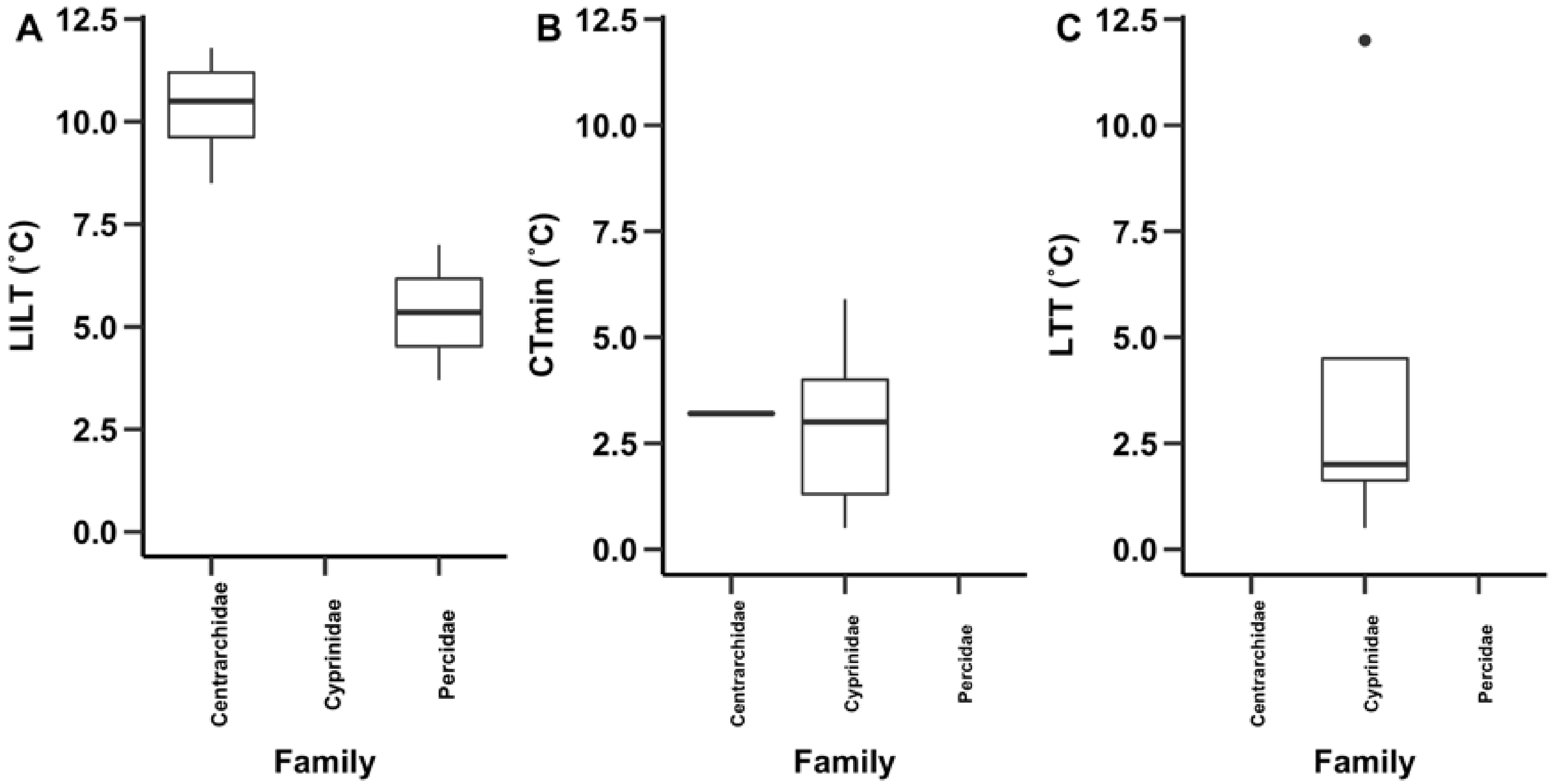

Figure 2. Distribution of thermal metrics describing the low temperature limits for identified species that are potentially invasive to the Prairie region grouped by family. (A) lower incipient lethal temperature (LILT), (B) critical thermal minimum (CT_{min}), and (C) lower lethal temperature (LLT).

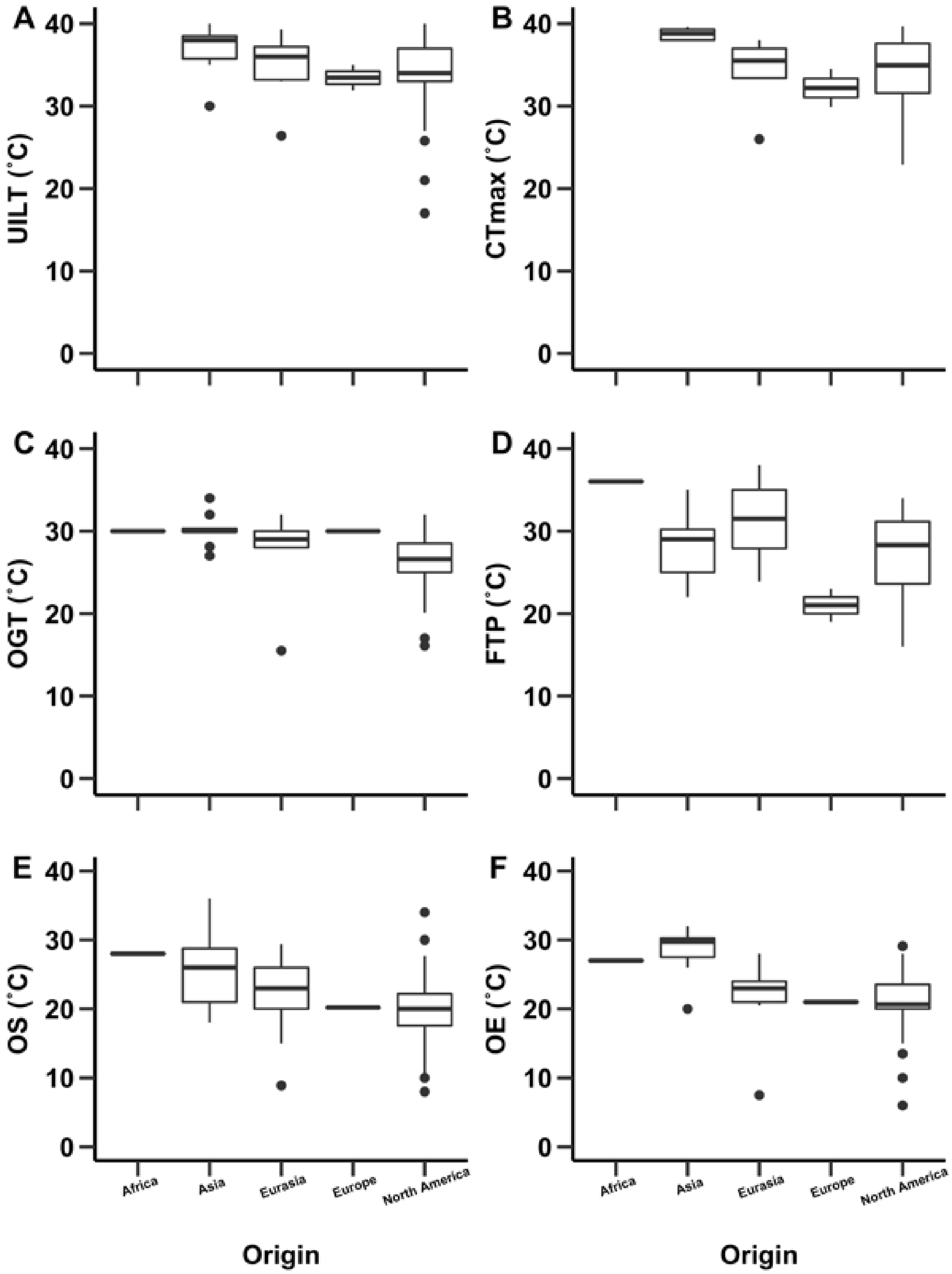

Figure 3. Distribution of thermal metrics describing the upper temperature limits and optimal temperatures for identified species of being currently or potentially invasive to the Prairie region grouped by origin. Note, species native to both eastern Europe and western Asia (i.e., west of the Ural mountains) were classified as originating in Eurasia. (A) upper incipient lethal temperature (UILT), (B) critical thermal maximum (CT_{max}), (C) optimal growth temperature (OGT), (D) final temperature preferendum (FTP), (E) optimal spawning temperature (OS), and (F) optimal egg development temperature (OE).

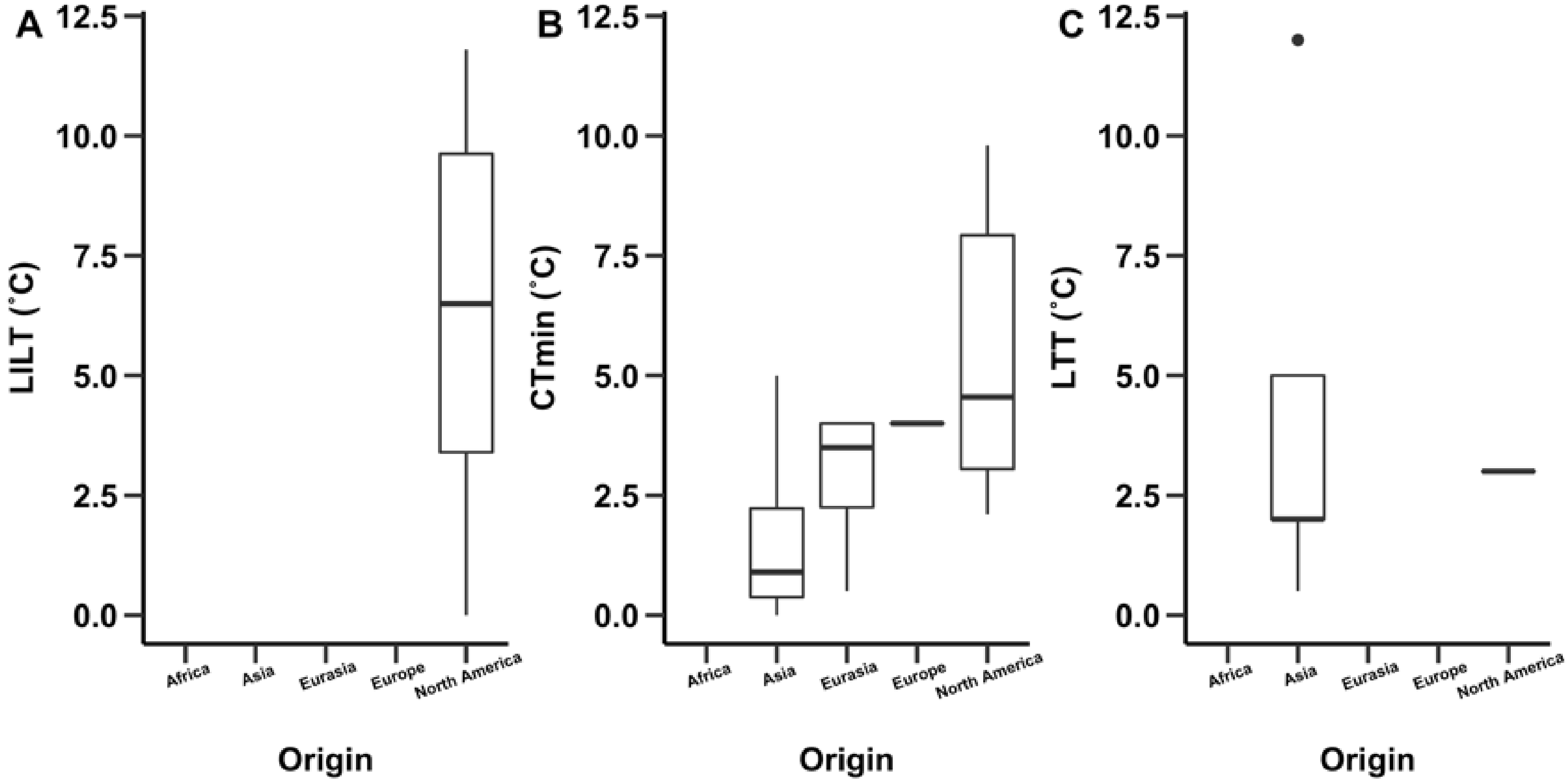

Figure 4. Distribution of thermal metrics describing the lower temperature limits for identified species of being currently or potentially invasive to the Prairie region grouped by geographic origin. (A) lower incipient lethal temperature (LILT), (B) critical thermal minimum (CT_{min}), and (C) lower lethal temperature (LLT). Thermal limit below 0 ºC relates to species occuring in brackish water.

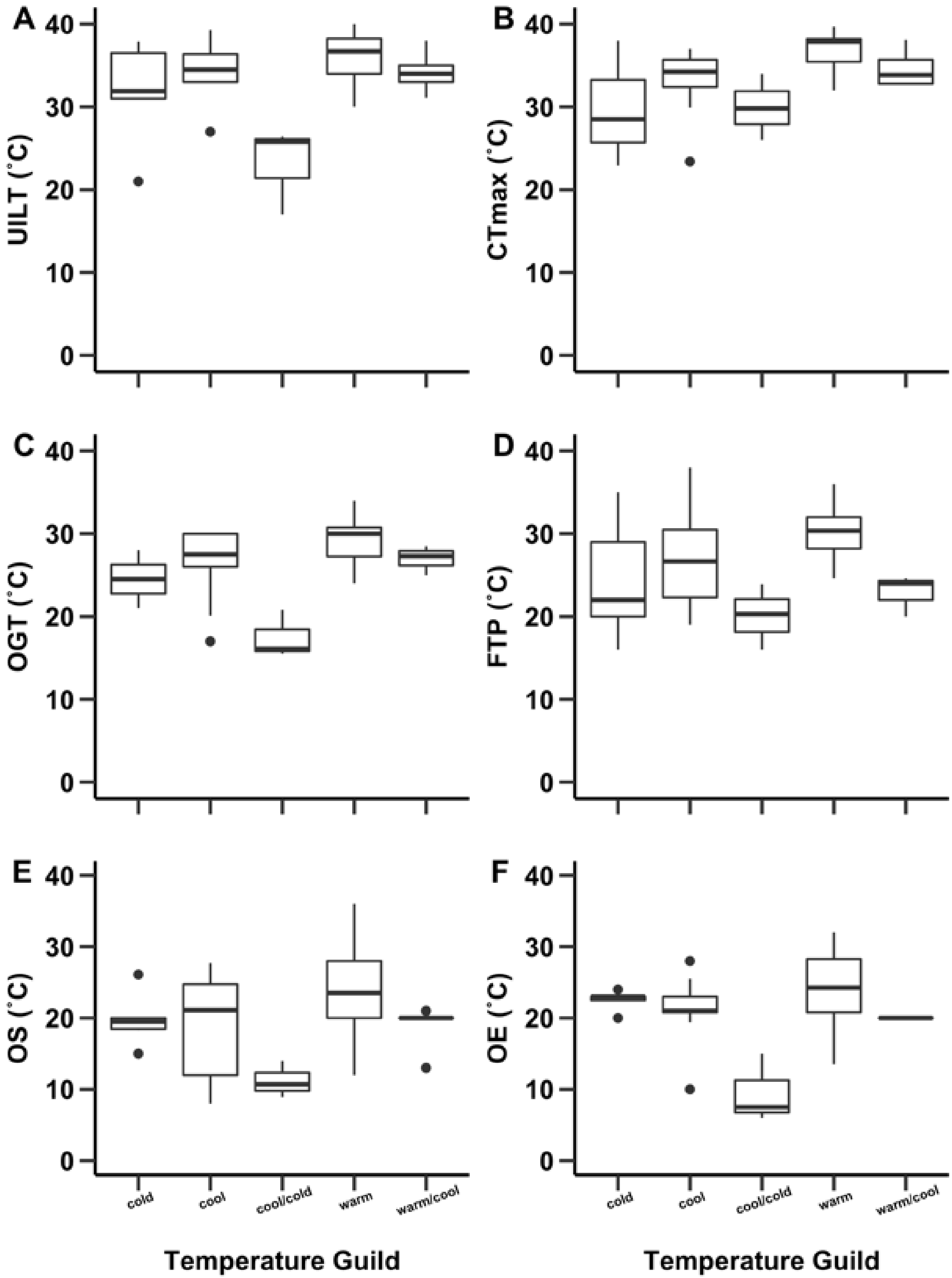

Figure 5. Distribution of thermal metrics describing the upper temperature limit for identified species potentially invasive to the Prairie region grouped by temperature guild. (A) upper incipient lethal temperature (UILT), (B) critical thermal maximum (CT_{max}), (C) optimal growth temperature (OGT), final temperature preferendum (FTP), (E) optimal spawning temperature (OS), and (F) optimal egg development temperature (OE).

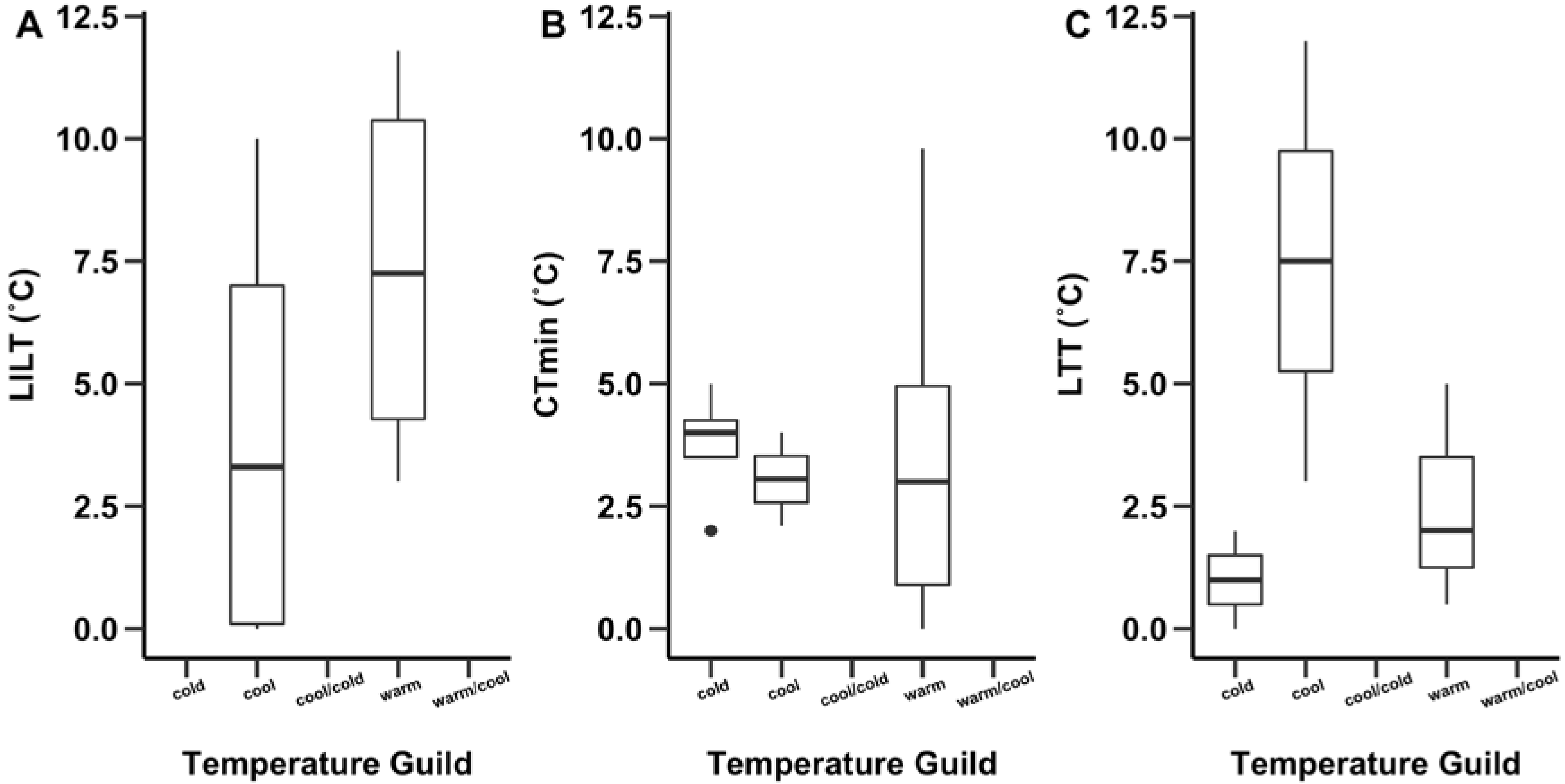

Figure 6 Distribution of the lower thermal metrics for identified species potentially invasive to the Prairie region grouped by temperature guild. (A) lower incipient lethal temperature (LILT), (B) critical thermal minimum (CT_{min}), and (C) lower lethal temperature (LLT). Thermal limit below 0 ºC relates to species occurring in brackish water.

RESEARCH OPPORTUNITIES AND KNOWLEDGE GAPS

1) Several potentially invasive species are likely to have the ability to overwinter in the Prairie region (e.g., Alewife, Grass Carp, Orfe, Round Goby, Rudd, Stone Moroko, Tench, Tubernose Goby, Zander). Further data, specifically related to their tolerance for lower temperatures, should be collected.

2) There were many data gaps for native fishes (see Table 2 and 3; e.g., Central Mudminnow, Bigmouth Buffalo, Flathead Chub, Tadpole Madtom). With growing concern related to climate change and the warming of local inland waters, thermal metric data should be collected for native fishes to quantify how fish communities may shift. Data that were particularly lacking were optimal growth and reproduction metrics as well as lower temperature metrics (CT_{min}, LILT, LTT).

3) Clear data gaps were identified for eleven fish species including fish with invasive tendencies in nearby regions (e.g., Bighead Carp, Silver Carp, Black Carp) and fish with invasive tendencies nearer to their geographic origin but not yet found in North America (e.g., Amur Bitterling, Eurasian Ruffe). Thermal metric data should be collected for Amur Bitterling, Alligator Gar, Bighead Carp, Black Carp, Eurasian Ruffe, Golden Trout, Green Sunfish, Ohrid Trout, Red Shiner, Silver Carp, and White Perch to fill the current data gaps.

4) The general lack of data made comparisons between taxonomic families, evolutionary origin, and temperature guilds difficult. But understanding of these relationships may not be necessary to predict the likelihood of species-specific invasion because wide variation in some groups were noted. It would be infomative, once more lower and upper thermal metrics are collected, to repeat this analyses to determine if valid conclusions can be reached.

5) Finally, a risk assessment for the Prairie region that includes an analysis of potential vectors and suitable waterbodies for the identified species would be useful for potential mitigation and prevention of the establishment of non-native species.

CONCLUSIONS

Based on the review of provincial and state agency webpages and discussions with local experts, 68 species were deemed to be of interest as potential invaders to the Prairie region or are known to the Prairie region and have invasive tendencies where they have been introduced. Thirty (44 %) of the identified species are known to overwinter in the Prairie region, and therefore, typical winter conditions in the Prairie region are not a hindrance to the spread of these species. Nine species thought to have the opportunity to invade the Prairie region had lower temperature metrics indicative of them having the ability to overwinter in the region. Insufficient data was available to assess the likelihood eleven species could survive winter conditions typical of the Prairie region, and given their current distributions and habitat needs, should be considered as significant knowledge gaps. No temperature data were found for ten species but the majority of these species are unlikely to tolerate typical Prairie winter temperatures. Several research opportunities have been identified to reduce knowledge gaps and should be considered so that future risk assessments can adequately determine the likelihood of species invasion.

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APPENDIX

Table A1. Upper incipient lethal temperature (UILT) and critical thermal maxium (CT_{max}) for the identified species. Species are only included if data were verifiable and temperatures are reported in degrees Celsius (°C). Data is included as reported in the cited reference. A dash (-) indicates information not available.

Species	UILT	UILT Reference	CT_{max}	CT_{max} Reference
Acipenser medirostris	17	Hasnain 2012	34.2	Sardella 2008
(Green Sturgeon)			33.7	Sardella 2008
			34	Hasnain 2012
Alosa pseudoharengus	23.5	Spotila et al. 1979	30.2	Wismer and Christie 1987
(Alewife)	24.5	Spotila et al. 1979	30.6	Wismer and Christie 1987
	22.8	Wismer and Christie 1987	32.6	Wismer and Christie 1987
	23.2	Wismer and Christie 1987	31–34	Wismer and Christie 1987
	28.2	Wismer and Christie 1987	32	Hasnain et al. 2010
	31.4	Wismer and Christie 1987		
	33.3	Wismer and Christie 1987		
	31–34	Wismer and Christie 1987		
	23	Hasnain et al. 2010		
	33.3	Hasnain et al. 2010		
Ameiurus melas	35	Carlander 1969	38.1	Smale and Rabeni 1995
(Black Bullhead)			37.5	Talmage and Coutant 1978
Ameiurus natalis	-	-	37.9	Smale and Rabeni 1995
(Yellow Bullhead)			36.4	Spotila et al. 1979
Ameiurus nebulosus	36	Scott and Crossman 1973	37.8	Spotila et al. 1979
(Brown bullhead)	28.6–37.5	Carlander 1969	38	Brown 1974
	29–41	Spotila et al. 1979		
Amia calva	-	-	37	Reutter and Herdendorf 1976
(Bowfin)				
Carassius auratus	41	Fry and Hart 1948	36	Weatherley 1970
(Goldfish)	38.6	Jobling 1981	39	Weatherley 1970
	29–38.6	Wismer and Christie 1987	35	Wismer and Christie 1987
	29.9–41	Wismer and Christie 1987	36.6	Wismer and Christie 1987
	41	Ford and Beitinger 2005	34.5	Ford and Beitinger 2005
			39.6	Ford and Beitinger 2005
Channa argus	35	Qin et al.1997	38	Qin et al. 1997
(Northern Snakehead)				
Channa maculata	38	Kunci 2017	41	Kunci 2017
(Blotched Snakehead)				
Ctenopharyngodon idella	34–39	Lehtonen 1996	39.3	Bettoli et al. 1985
(Grass Carp)			39.3	Chilton and Muoneke 1992
Cyprinella lutrensis	39	Matthews and Hill 1777	39.5	Brues 1928
(Red Shiner)	39	Matthews and Maness 1979	35.9–36.3	Matthews 1986
			39.7	Rutledge and Beitinger 1989

Cyprinus carpio	34.5	Edwards and Twomey 1982	39	Reutter and Herdendorf 1976
(Common Carp)	36.7	Lechleitner 1992	39.7	Chatterjee et al. 2004
	40.6	Lechleitner 1992	40.6	Chatterjee et al. 2004
	39.8	Chatterjee et al. 2004	38–41	Golovanov 2013
	40.9	Chatterjee et al. 2004		
	35.7	NDEP 2016		
	31–34	NDEP 2016		
	35.5–37	NDEP 2016		
	38–39	NDEP 2016		
Esox lucius	29.4	Casselman 1978	33.25	Brown 1974
(Northern Pike)	30	Casselman 1978		
	33	Spotila et al. 1979		
	29	Casselman 1978		
Esox masquinongy	29	Jobling 1981	32	Hasnain 2012
(Muskellunge)	34	Jobling 1981		
Gambusia affinis	39	Hagen 1964	37.4	Otto 1973
(Western Mosquitofish)	36	Otto 1973	38.8	Otto 1973
	38	Otto 1973	39.5	Otto 1973
	38	Cherry et al. 1976	41.4	Otto 1973
	37.3	Jobling 1981	42.3	Otto 1973
	35–40	Chipps and Wahl 2004	36	Beitinger et al. 2000
			38	Beitinger et al. 2000
			41	Beitinger et al. 2000
			43	Chipps and Wahl 2004
Gymnocephalus cernuus	30.4	Hokanson 1977	34.5	Hokanson 1977
(Ruffe)	28–35	Lehtonen 1996	30	Tarvainen et al. 2008
	20–28	Tarvainen et al. 2008		
	28.1	Souchon and Tissot 2012		
Hypophthalmichthys molitrix	43	Cooke and Hill 2010	-	-
(Silver Carp)	43.5–46.5	Schofield and Huge 2011		
Hypophthalmichthys nobilis	38	Cooke and Hill 2010	38.8	Bettoli et al. 1985
(Bighead Carp)				
Ictalurus punctatus	30.3	Hart 1952	40.3	Currie et al. 1998
(Channel Catfish)	32.8	Hart 1952	34.5–41	Cheetham et al. 1976
	33.5	Hart 1952	38–42.1	Bennett et al. 1998
	32.7	Hart 1952		
	36.6	Allen and Strawn 1967		
	37.3	Allen and Strawn 1967		
	37.8	Allen and Strawn 1967		
Lepomis cyanellus	40	Hasnain 2012	35.8	Carrier and Beitinger 1988b
(Green Sunfish)			35.9	Smale and Rabeni 1995
			37.9	Lutterschmidt and Hutchison 1997
			34.2	Lutterschmidt and Hutchison 1997
			36	Hasnain 2012

Lepomis gibbosus	34.5	Carlander 1977	30.1	Becker and Genoway 1979
(Pumpkinseed)	24.5	Leidy and Jenkins 1977	35.1	Reutter and Herdendorf 1976
	36.6	Jobling 1981	37.5	Reutter and Herdendorf 1976
	34.8	Jobling 1981		
	27.7–37	Evans 1977		
Lepomis macrochirus	31	EPA 1974	38.3	Reutter and Herdendorf 1976
(Bluegill)	32	EPA 1974	41.5	Reutter and Herdendorf 1976
	34	EPA 1974		
Leuciscus idus	37.9	Horoszewicz 1973	-	-
(Ide/Orfe)	24–27	Lehtonen 1996		
	24–29	Schofield et al. 2005		
Micropterus dolomieu	37	Ellis 1984	36.3	Reutter and
(Smallmouth Bass)	35	Wrenn 1980		Herdendorf 1976
Micropterus salmoides	32.5	Hart 1952	38.5	Currie et al.1998
(Largemouth Bass)	34.5	Hart 1952	36.7–40.1	Smith and Scott 1975
	36.4	Hart 1952	33.6–41.8	Fields et al. 1987
	31.8	Hart 1952		
	32.7	Hart 1952		
	33.7	Hart 1952		
	28.9	Hart 1952		
	35.6	Black 1953		
Misgurnus anguillicaudatus	30	Strecker et al. 2011	38	Urquhart 2013
(Japanese Weatherfish)				
Morone Americana	33	Stanley and Danie 1983	34	Stanley and Danie 1983
(White Perch)	36	Hasnain et al. 2010	35.5	Stanley and Danie 1983
Morone chrysops	30–32	Ellis 1984	35.3	Reutter and Herdendorf 1976
(White Bass)	36.1	Talmage and Coutant 1978		
Mylopharyngodon piceus	40	NACA 1989	-	-
(Black Carp)				
Neogobius melanostomus	25.7	Lee and Johnson 2005	31.5	Cross and Rawding 2009
(Round Goby)	33.4	Xin 2016	33.4	Cross and Rawding 2009
Notropis hudsonius	30.6	Brown 1974	32.8	Reutter and
(Spottail Shiner)	31.1	Brown 1974	-	Herdendorf 1979
Noturus gyrinus	-	-	38	Beltz et al. 1974
(Tadpole Madtom)				
Oncorhynchus aquabonita	-	-	27.7	Myrick and Cech 1999
(Golden Trout)			28.3	Myrick and Cech 1999
			29.6	Myrick and Cech 1999
			30.3	Myrick and Cech 1999
Oncorhynchus mykiss	24	Black 1953	29.8	Currie et al. 1998
(Rainbow trout)	26.5	Alabaster and Welcomme 1962	28.2–29.5	Lee and Rinne 1980
	27	Craigie 1963	28.8–30.0	Strange et al. 1993
	24.3	Alabaster 1964		

	25.9	Alabaster 1964		
	25–26	Cherry et al. 1977		
	25.6	Hokansen et al. 1977		
	23.2–26.2	Kaya 1978		
	22.6–25.9	Threader and Houston 1983		
Oreochromis niloticus	37	Baras et al. 2001	40	Azaza et al. 2008
(Nile tilapia)	38.5–39	Baras et al. 2001	42	Froese and Pauly 2017c
	42	FAO 2008		
Osmerus mordax	18	Lantry and	28.5	Wismer and Christie 1987
(Rainbow smelt)	21	Steward 1993	19–28.5	Wismer and Christie 1987
		Lawson et al. 2015	18	Lawson et al. 2015
Perca flavescens	21	EPA 1974	35	Reutter and
(Yellow Perch)	25	EPA 1974		Herdendorf 1976
	28	EPA 1974		
	32.3	EPA 1974		
Percopsis omiscomaycus	-	-	22.9	Reutter and Herdendorf 1976
(Troutperch)				
Petromyzon marinus	25	Kitchell and Breck 1980	-	-
(Sea Lamprey)	31	Jobling 1981		
Pimephales promelas	28.2	Brown 1974	32.4	Spieler et al. 1977
(Fathead Minnow)	31.7	Brown 1974	34	Spieler et al.1997
	33.2	Brown 1974	33.2	Maness and Hutchinson 1980
			35.1	Watenpaugh and Beitinger 1985
			34.8	Carrier and Beitinger 1988a
			34.9	Carrier and Beitinger 1988a
			33.1	Carrier and Beitinger 1988a
			36.9	Castelberry and Cech 1992
			36.2	Pyron and Beitinger 1993
			36.7	Pyron and Beitinger 1993
			28.6	Pyron and Beitinger 1993
			30.7	Pyron and Beitinger
			36.4	Heath et al. 1994
			40.4	Richards and Beitinger 1995
Poecilia latipinna	-	-	38.7	Yanar et al. 2019
(Sailfin Molly)			40.2	Yanar et al. 2019
			41.8	Yanar et al. 2019
Pomoxis annularis	< 33	EPA 1974	32.8	Reutter and Herdendorf 1976
(White Crappie)				
Pomoxis nigromaculatus	34	Carlander 1977	34.9	Reutter and Herdendorf 1976
(Black Crappie)	32.5	Leidy and Jenkins 1977		
Proterorhinus semilunaris	31.9	Xin 2016	-	-
(Freshwater Tubenose Goby)				
Rhodeus sericeus	35.7–36.5	Horoszewicz 1973	-	-

(Amur Bitterling)				
Salmo letnica (Ohrid Trout)	-	-	29 29.8 29.9	Lee and Rinne 1980 Elliot and Elliot 1995 Elliot and Elliot 1995
Salmo trutta (Brown Trout)	23 26.4	Cherry et al. 1977 Jobing 1981	25 26	Spotila 1979 Spotila 1979
Salvelinus fontinalis (Brook Trout)	24 24.9 25.8	Cherry et al. 1977 Brown 1974 Brown 1974	28.7 29.8 -	Lee and Rinne 1980 Lee and Rinne 1980
Sander lucioperca (Zander)	34.3 35 30–31 36 31–33	Horoszewicz 1973 Hokanson 1977 Keskinen et al. 2008 Frisk et al. 2012 Smith and Koenst 1975	33 35 34.5–35.5	Horoszewicz 1973 Keskinen et al. 2008 Golovanov 2013
Scardinius erythrophthalmus (Rudd)	35–36.5	Horoszewicz 1973	29–38	Lehtonen 1996
Silurus glanis (Wels Catfish)	33	Souchon and Tissot 2012	-	-
Tinca tinca (Tench)	37.8–39.3 32.3	Horoszewicz 1973 Schofield et al. 2005	37	Cudmore and Mandrak 2011
Umbra limi (Central Mudminnow)	38 33.5	Beltz et al. 1974 Hasnain 2012	-	-

Table A2. Optimal growth temperature (OGT) and final temperature preferendum (FTP) for the identified species. Species are only included if data were verifiable and temperatures are reported in degrees Celsius (°C). Data is included as reported in the cited reference. A dash (-) indicates information not available.

Species	OGT	OGT Reference	FTP	FTP reference
Acipenser medirostris (Green Sturgeon)	11–19	Mayfield and Cech 2004	15–16	Mayfield and Cech 2004
	15	Cech et al. 2000		
	20.8	Hasnain 2012		
Alosa pseudoharengus (Alewife)	20.1	Hasnain et al. 2010	16	Spotila et al. 1979
			19.6	Spotila et al. 1979
			21.3	Spotila et al. 1979
			26.5	Spotila et al. 1979
			17.2	Wismer and Christie 1987
			11–16	Wismer and Christie 1987
			16–21	Wismer and Christie 1987
			27.8–28.3	Wismer and Christie 1987
Ameiurus natalis (Yellow Bullhead)	-	-	28.3	Coutant 1977
			28.8	Coutant 1977
			27.6	Coutant 1977
			28.2	Hasnain 2012
Ameiurus nebulosus (Brown bullhead)	32	Jobling 1981	11.9–31	Coutant 1977
	28.2–29.9	Richards and Ibara 1978		
Amia calva (Bowfin)	-	-	30.5	Houston 1982
			30.3	Hasnain 2012
Carassius auratus (Goldfish)	25	Jobling 1981	28–29	Fry and Hart 1948
	28.1	Wismer and Christie 1987	25.3	Spotila et al.1979
			27	Spotila et al.1979
			28.1	Spotila et al.1979
			28	Jobling 1981
Carassius gibelio (Prussian Carp)	-	-	5.2–27.1	Tarkan et al.2007
Channa argus (Northern Snakehead)	26.1	Liu et al. 1998	30	Qin et al. 1997
	30.3	Liu et al. 1998	28.6	Liu et al. 1998
	23–29	Kunci 2017	30	Lapointe et al. 2010
	25–30	Liu et al. 2002	14–33	Kunci 2017
			30	Courtenay and Williams 2004
Channa maculata (Blotched Snakehead)	27	Qin and Fast 1998	20–35	Qin and Fast 1998

Ctenopharyngodon idella (Grass Carp)	20–30	Lehtonen 1996	25.3	Bettoli et al. 1985
	18.3–29.4	Cudmore and Mandrak 2004	29	Díaz et al. 1998
			25.8–30.2	Díaz et al. 1998
Cyprinella lutrensis (Red Shiner)	-	-	30	Calhoun et al. 1982
Cyprinus carpio (Common Carp)	20–28	Edwards and Twomey 1982	29.7	Reutter and Herdendorf 1976
	27.2	Lechleitner 1992	29	Jobling 1981
	26–32	Golovanov 2013	32	Lechleitner 1992
	27	NDEP 2016	31.5	Lechleitner 1992
	30–32	Jobling 1981	29–31	Golovanov 2013
Esox lucius (Northern Pike)	20.9	Casselman 1978	19–20	Casselman 1978
	19–21	McCauley and Casselmen 1980		
	26	EPA 1974		
Esox masquinongy (Muskellunge)	24–26.6	Jobling 1981	> 25.5	Minor and Crossman 1979
			14	Jobling 1981
			21.9	Talmage and Coutant 1980
			27.3	Talmage and Coutant 1980
			25.6	Scott and Crossman 1973
Gambusia affinis (Western Mosquitofish)	28.6	Jobling 1981	34.7	Cherry et al. 1976
	30	Pyke 2005	35.1	Jobling 1981
	30.9	Jobling 1981	31	Jobling 1981
			28	Jobling 1981
			31	Chipps and Wahl 2004
Gymnocephalus cernuus (Ruffe)	25–30	Hokanson 1977	19	Tarvainen et al. 2008
	18–22	Edsall et al. 1993		
	18	Hölker and Thiel 1998		
Hypophthalmichthys molitrix (Silver Carp)	33.5	Kolar et al. 2005	27.1	DeGrandchamp et al. 2008
	24–31	Kolar et al. 2005	29	Cooke and Hill 2010
	26–30	Kolar et al. 2005		
	30–34	Kolar et al. 2005		
Hypophthalmichthys nobilis (Bighead Carp)	25-30	Chen et al. 2007	25.4	Bettoli et al. 1985
			27	DeGrandchamp et al. 2008
			26	Cooke and Hill 2010
Ictalurus punctatus (Channel Catfish)	28–30	Jobling 1981	25.2	Spotila et al. 1979
			25.3	Spotila et al. 1979
			30.5	Spotila et al. 1979
			23–32.5	Spotila et al. 1979
			17–30	Spotila et al. 1979
Ictiobus cyprinellus (Bigmouth Buffalo)	-	-	6–24	Yoder and Gammon 1976
			18–26	Yoder and Gammon 1976
			22–23	Yoder and Gammon 1976

Lepomis cyanellus (Green Sunfish)	28	Carlander 1977	15.9	Carlander 1977
			22.7	Carlander 1977
			30.6	Carlander 1977
			26.8	Beltz et al.1974
Lepomis gibbosus (Pumpkinseed)	25	Hasnain 2012	24.2	Coutant 1977a
			27.7	Coutant 1977a
			28.5	Talmage and Coutant 1979
			31.7	Talmage and Coutant 1979
			22.9–30.3	Evans 1977
Lepomis macrochirus (Bluegill)	30–31	McCauley and Casselman 1980	31	Cravens 1982
	24–27	Brown 1974	27.4	Coutant 1977
			32	Coutant 1977
Leuciscus idus (Ide/Orfe)	-	-	4–35	Leuven et al. 2011
			4–20	CABI 2017a
Micropterus dolomieu (Smallmouth Bass)	25–27	McCauley and Casselmen 1980	12–31.3	Coutant 1977
			26.6	Cherry et al. 1977
Micropterus salmoides (Largemouth Bass)	18–25	Niimi and Beamish 1974	27–32	Talmage and Coutant 1979
Misgurnus anguillicaudatus (Japanese Weatherfish)	20–30	Nienhuis 2015	5–25	Strecker et al.2011
Morone Americana (White Perch)	24	Scott and Crossman 1973	28.9–32.5	Hall Jr et al. 1978
	28.5	Wismer and Christie 1987	32.5	Stanley and Danie 1983
			29.8	Hasnain et al. 2010
			26–30	Eakins 2017b
Morone chrysops (White Bass)	23–24	EPA 1974	12–17	Coutant 1977
	16	Brown 1974	28–30	Brown 1984
			30–34	Brown 1984
Mylopharyngodon piceus (Black Carp)	25–32	NACA 1989	-	-
	24–29	Li and Fang 1990		
Neogobius melanostomus (Round Goby)	-	-	24.6	Lee and Johnson 2005
Notropis hudsonius (Spottail Shiner)	27.3	Kellogg and Gift 1983	14	Coutant 1977a
			17–20	Crowder et al. 1981
Oncorhynchus mykiss (Rainbow Trout)	16.5–17	Jobling 1981	11.3	Jobling 1981
	12	Spotila et al. 1979	14	Jobling 1981
			15.8	Jobling 1981
			17.5	Spotila et al. 1979
			22	Spotila et al. 1979
			11.6	Spotila et al. 1979
			12.6	Spotila et al. 1979

Oreochromis niloticus	21	El-Sayed et al.1996	13.5–33	Froese and Pauly 2017c
(Nile Tilapia)	27	Likongwe et al. 1996	31–36	FAO 2008
	30	Soderberg 2006		
	30	Azaza et al. 2008		
	22–30	Azaza et al. 2008		
	20	Nienhuis 2013		
Osmerus mordax	-	-	12.8	Ferguson 1958
(Rainbow Smelt)			7.2	Scott and Crossman 1973
			6.6–8.3	IAEA 1975
			6–14	IAEA 1975
			6–16	Wismer and Christie 1987
			10	Lantry and Stewart 1993
			9.5	Pientka and Parrish 2002
			14.1	Pientka and Parrish 2002
			14.9–15.4	Pientka and Parrish 2002
			7–16	Eakins 2017a
Perca flavescens	22.5	McCauley and Casselman 1980	21	Coutant 1977
(Yellow Perch)	23	Smagula and Adelman1982	7–12	Coutant 1977
	26–30	Kitchell et al. 1977	13–16	Coutant 1977
			27	Coutant 1977
			22–25	Coutant 1977
Percopsis omiscomaycus	-	-	16–18	Brandt et al. 1980
(Trout Perch)			15–16	Brandt et al. 1980
			7–16	Crowder at al. 1981
			13.4	Hasnain 2012
Petromyzon marinus	15	Farmer et al. 1977	6–15	Farmer et al. 1977
(Sea Lamprey)	21	Rodriguez-Muñoz et al. 2001	18	Kitchell and Breck 1980
			13.6	Jobling 1981
			5–22	Leuven et al. 2011
			7.1	Froese and Pauly 2017d
Pimephales promelas	26	Jobling 1981	28.5	Coutant 1977
(Fathead Minnow)	25.5	Jobling 1981	29	Coutant 1977
Pomoxis annularis	25	EPA 1974	19.8	Coutant 1977
(White Crappie)	27–28.5	Yoder and Gammon 1976	18.3	Coutant 1977
			10.4	Coutant 1977
			19.4	Reutter and Herdendorf 1976
			23–24	O'Brien et al. 1984
Pomoxis nigromaculatus	22–25	Brown 1974	20.5–24	Coutant 1977
(Black Crappie)			24.6	Reutter and Herdendorf 1976
Proterorhinus semilunaris	-	-	22–23	Golovanov 2013

(Freshwater Tubenose Goby)			11–18.3	Froese and Pauly 2018
Pseudorasbora parva	-	-	5–22	Kerr 2014a
(Stone Moroko)				
Rhodeus sericeus	24.3	Jobling 1981	25	Coutant 1977
(Amur Bitterling)	29.9	Jobling 1981	14–21	Leuven et al. 2011
	12–24.3	Souchon and Tissot 2012		
Salma trutta	10	Jobling 1981	18–24	Scott and Crossman 1973
(Brown Trout)	15.5	McCauley and Casselmen 1980	13.8	Coutant 1977
	12	McCauley and Casselmen 1980		
	12.8	McCauley and Casselmen 1980		
Salvelinus fontinalis	13	Jobling 1981	< 20	Scott and Crossman 1973
(Brook Trout)	14	Brown 1974	19	Coutant 1977
	16.1	Brown 1974	20.3	Coutant 1977
	15.4	Brown 1974	20	Coutant 1977
			15.7	Coutant 1977
			14.8	Coutant 1977
Sander lucioperca	27.3	Hokanson 1977	29	Hokanson 1977
(Zander)	24–29	Hokanson 1977	24	Keskinen et al. 2008
	28–30	Hokanson 1977	22–26	Golovanov 2013
	24–28	Wang et al. 2009	6–22	Kerr 2014a
	10–27	Frisk et al. 2012		
	24–30	Kerr 2014a		
Sander vitreus	20–26	McMahon et al. 1984	20–23	Ferguson 1958
(Walleye)	19–25	Kokanson and Koenst 1986	20.6–23.2	Coutant 1977
	20	Colby et al. 1979		
	23–24	Nickum 1986		
Scardinius erythrophthalmus	14–28	Lehtonen 1996	2–35	Leuven et al. 2011
(Rudd)				
Silurus glanis	25–28	Copp et al. 2009	4–20	Leuven et al. 2011
(Wels Catfish)	12–28	Souchon and Tissot 2012	30	Nienhuis 2016
	25–27	Santoul 2017	31	Nienhuis 2016
Tinca tinca	12–30	Schofield et al. 2005	15–23.5	Cudmore and Mandrak 2011
(Tench)			20–24	Cudmore and Mandrak 2011
			20–27	Cudmore and Mandrak 2011
			4–38	Leuven et al. 2011

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Table A3. Optimal spawning temperature (OS) and optimal egg development temperature (OE) for the identified species. Species are only included if data were verifiable and temperatures are reported in degrees Celsius (°C). Data is included as reported in the cited reference.

Species	OS	OS Reference	OE	OE Reference
Acipenser medirostris	8–14	Elkins et al. 2001	15	Hasnain
(Green Sturgeon)	12.1	Hasnain 2012		
Alosa pseudoharengus	12.9–13.1	Tyus 1974	17.7	Spotila et al. 1979
(Alewife)	13–16	Richkus 1974	20.8	Wismer and Christie 1987
	15.6–27.7	Spotila et al. 1979		
	17.8	Wismer and Christie 1987		
	22	Wismer and Christie 1987		
	12.9–13.1	Wismer and Christie 1987		
	13–21	Wismer and Christie 1987		
	13–16	Wismer and Christie 1987		
Ameiurus melas	21	Scott and Crossman 1973	-	-
(Black Bullhead)				
Ameiurus nebulosus	21.1	Scott and Crossman 1973	-	-
(Brown Bullhead)				
Amia calva	16–19	Scott and Crossman 1973	-	-
(Bowfin)				
Carassius auratus	17–24	Wismer and Christie 1987	18.5–29.5	Wismer and Christie 1987
(Goldfish)				
Carassius gibelio	14	Paschos et al. 2004	20.5	Saat and Veersalu 1996
(Prussian Carp)	13.5–29.4	Sasi 2008		
	18–19	Kirankaya and Ekmekçi 2013		
Channa argus	24	Landis et al. 2011	31	Courtenay and Williams 2004
(Northern Snakehead)	26	Landis et al. 2011	25–30	Kunci 2017
	18–20	Landis et al. 2011		
	18	Lapointe et al. 2013		
	25	Lapointe et al. 2013		
	24–29	Kunci 2017		
Channa maculata	25–28	Wan Yaakov and Ali 1992	-	-
(Blotched Snakehead)				
Ctenopharyngodon idella	25	Shireman and Smith 1983	26	Fedorenko and Fraser 1978
(Grass Carp)	22	Chilton and Muoneke 1992	22–26	Nico and Williams 1996
	30	Chilton and Muoneke 1992	32	Korwin-Kossakowski 2008

Cyprinella lutrensis (Red Shiner)	30–34	Gale 1986	24.5	NatureServe 2016
Cyprinus carpio (Common Carp)	18–23 23 16–22 18 15.5–22 15–20	Edwards and Twomey 1982 Lechleitner 1992 Mann 1996 Freyhof and Kottelat 2008b Golovanov 2013 Froese and Pauly 2017e	21 29.5 21 16–23	Lechleitner 1992 Lechleitner 1992 Saat and Veersatu 1996 Golovanov 2013
Esox lucius (Northern Pike)	< 10	Talmage and Coutant 1979	20.8 6.4–17.7	Cravens et al. 1982 Spotila et al. 1979
Esox masquinongy (Muskellunge)	13 16–18 13 12.8	Haas 1978 Talmage and Coutant 1979 Carlander 1977 Scott and Crossman 1973	13.5	Hasnain 2012
Gambusia affinis (Western mosquitofish)	5–20 12–23	Wismer and Christie 1987 Boulé and Fitzgerald 1989	19–20 19	Wallace and Selman 1979 Wismer and Christie 1987
Gymnocephalus cernuus (Ruffe)	11.6–18 12–18 6–20 6–18 7.1–20.2 12–14 6–18	Hokanson 1977 Hokanson 1977 Mann 1996 Ogle 1998 Kováč 1998 Brown et al.1998 Souchon and Tissot 2012	21 9–21 11–15 16–18 11–20	Fairchild and McCormick 1996 Saat and Veersalu 1996 Ogle 1998 Bonislawska et al. 2004 Froese and Pauly 2017b
Hypophthalmichthys molitrix (Silver carp)	21–26 14 18–20	Schofield et al. 2005 Kipp et al. 2011 GISD 2017	24–25 22.3	Schoonbee and Prinsloo 1984 Chapman and George 2011
Hypophthalmichthys nobilis (Bighead Carp)	22–25.5 25–30 22 24.4–28.2 18 18–26 18.5–29.7	Jennings 1988 Jennings 1988 Schrank et al. 2001 Schofield et al. 2005 Peters et al. 2006 Chen et al. 2007 Coulter et al. 2013	22–26 24–30 25	Jennings 1988 Jennings 1988 Coulter at al. 2013
Ictalurus punctatus (Channel Catfish)	26.7 23.9	Scott and Crossman 1973 Carlander 1969	22	Brown 1974
Ictiobus cyprinellus (Bigmouth Buffalo)	15.5–18.3 17	Scott and Crossman 1973 EPA 1974	20.5	Hasnain 2012
Lepomis cyanellus (Green Sunfish)	16.7 21.9	Brown 1974 Hasnain 2012	29.1	Carlander 1977
Lepomis gibbosus	25	Jobling 1981	28	Brown 1974

(Pumpkinseed)	30	Griffiths 1978		
	28	Brown 1974		
	24	Brown 1974		
Lepomis macrochirus	25	EPA 1974	22.2-23.9	Spotila et al. 1979
(Bluegill)			22-24	EPA 1974
Leuciscus idus	4–10	EIFAC 1969	12–18	Schofield et al. 2005
(Ide/Orfe)	4–15	Mann 1996	15.7	Kupren et al. 2008
	7–14	Schofield et al. 2005	9.5–23	Kupren et al. 2008
	14.5	Kucharczyk et al. 2008		
	12	Corolla and Kupfer 2017		
Micropterus dolomieu	18	Shuter et al. 1980	21	EPA 1974
(Smallmouth Bass)				
Micropterus salmoides	15.6–21	Carlander 1977	20	EPA 1974
(Largemouth Bass)	20	Carlander 1977		
Misgurnus anguillicaudatus	20	Nienhuis 2015	25–30	Suzuki and Yamaguchi 1977
(Japanese Weatherfish)			23	Wang et al. 2010
Morone Americana	11–16	Scott and Crossman 1973	20	Scott and Crossman 1973
(White Perch)	15.6–19.4	Wismer and Christie 1987	18	Morgan et al. 1981
	15–20	CABI 2017b	19–20.9	Wismer and Christie 1987
	10–16	CABI 2017b	15	CABI 2017b
Morone chrysops	14.7–16.3	Talmage and Coutant 1978	16–17	EPA 1974
(White Bass)			23.9	Brown 1974
Mylopharyngodon piceus	22–28	NACA 1989	21–24	Nico and Williams 1996
(Black Carp)	18–25	Nico and Williams 1996	25–28	Kamal et al.2006
	26–36	Nico and Williams 1996		
	18–29	CDFW 2013		
Neogobius melanostomus	9–26	Gertzen et al. 2016	19–21	Gertzen et al. 2016
(Round Goby)				
Notropis hudsonius	20	Carlander 1969	20	Brown 1974
(Spottail Shiner)	18	Mansfield 1984		
Oncorhynchus mykiss	6–8	Brown 1974	7–10	Spotila et al. 1979
(Rainbow Trout)				
Oreochromis niloticus	22	Duponchelle et al. 1999	27	Bezault et al. 2007
(Nile Tilapia)	27–28	Baras et al. 2001		
	21	Nienhuis 2013		
	22	Nienhuis 2013		
	24	FAO 2008		
Osmerus mordax	8.9–18.3	Scott and Crossman 1973	11–17	Wismer and Christie 1987
(Rainbow Smelt)	10–15	Scott and Crossman 1973	14	Wismer and Christie 1987
	10	Wismer and Christie 1987	22.5	Wismer and Christie 1987

	4.5–11	Eakins 2017a	14–16	Bradbury et al. 2004
Perca flavescens (Yellow Perch)	12	EPA 1974	10–20	EPA 1974
	5–6	Dunford 1978		
Percopsis omiscomaycus (Troutperch)	15	Talmage and Coutant 1978	-	-
	20	Carlander 1969		
Petromyzon marinus (Sea Lamprey)	26.1	Manion and Hanson 1980	18.4	Scott and Crossman 1973
	17–19	Beamish 1980	18.5	Wismer and Christie 1987
	14–18.2	Wismer and Christie 1987	11–23	Rodriguez-Muñoz et al. 2001
	14.4–15.6	Hasnain et al. 2010	15–19	Rodriguez-Muñoz et al. 2001
	18–23	Froese and Pauly 2017d		
Pimephales promelas (Fathead Minnow)	< 23.5	Beltz et al. 1974	25	Wismer and Christie 1987
Pomoxis annularis (White Crappie)	16–20	EPA 1974	-	-
	18–20	EPA 1974		
	14–16	O'Brien et al. 1984		
Pomoxis nigromaculatus (Black Crappie)	17.8–20	Carlander 1977	18.3	Carlson and Herman 1978
	19–20	Carlander 1977	16–20	Wismer and Christie 1987
Pseudorasbora parva (Stone Moroko)	15–19	Hubble 2012	20	Pinder and Gozlan 2003
Rhodeus sericeus (Amur Bitterling)	12–24	Schofield et al. 2005	-	-
	15–21	Souchon and Tissot 2012		
Salmoa trutta (Brown Trout)	6.7–8.9	Scott and Crossman 1973	7.5	Hasnain 2012
Salvelinus fontinalis (Brook Trout)	10.7	Brown 1974	6	Brown 1974
Sander lucioperca (Zander)	12–20	Hokanson 1977	14–23	Hokanson 1977
	8–22	Mann 1996	12–16	Lappalainen et al. 2003
	8–16	Lappalainen et al. 2003	12–20	Larsen and Berg 2014
	13–19	Fontell et al. 2004	20	Kerr 2014a
	10–14	Kerr 2014a		
	10–14	Kerr 2014a		
	12	Kerr 2014a		
	12	Kerr 2014a		
	10–14.5	Kerr 2014a		
	8–15	FAO 2012		
Sander vitreus (Walleye)	6–12	Smith and Koenst 1975	6	Hokanson 1977
	6.1–8.3	Smith and Koenst 1975	9–15	Smith and Koenst 1975
	7.8–8.9	Smith and Koenst 1975	17.8–19.4	Smith and Koenst 1975
	7.2–10	Smith and Koenst 1975	16.7	Talmage and Coutant 1980
	4.4–6.7	Smith and Koenst 1975		

	3.4–10	Smith and Koenst 1975		
	5–10	Smith and Koenst 1975		
	7.1–9.9	Spotila et al. 1979		
Scardinius erythrophthalmus	18–24	EIFAC 1969	24	Korzelecka and Winnicki 1998
(Rudd)	14–20	Mann 1996	17.5–21.5	Schofield et al. 2005
	16	Schofield et al. 2005		
	18	CABI 2017c		
Silurus glanis	20–25	Souchon and Tissot 2012	23–25	Copp et al. 2009
(Wels Catfish)	18	Nienhuis 2016	22–25	Souchon and Tissot 2012
	20	Nienhuis 2016	20–28	Santoul 2017
	20	Santoul 2017		
Tinca tinca	19–25	EIFAC 1969	19–24	Horoszewicz 1973
(Tench)	16–26	Mann 1996	22–24	Schofield et al. 2005
	18	Schofield et al. 2005	19–25.5	Korwin-Kossakowski 2008
	19	Freyhof and Kottelat 2008b	22.9	Cudmore and Mandrak 2011
	22–24	Freyhof and Kottelat 2008b		
Umbra limi	13	Carlander 1969	-	-
(Central Mudminnow)	12.8	Scott and Crossman 1973		

Table A4. Lower incipient lethal temperature (LILT) and critical thermal minimum (CT_{min}) for the identified species. Species are only included if data were verifiable and temperatures are reported in degrees Celsius (°C). Data is included as reported in the cited reference. A dash (-) indicates information not available.

Species	LILT	LILT Reference	CT_{min}	CT_{min} reference
Alosa pseudoharengus (Alewife)	0	Snyder and Hennessey 2003	-	-
Carassius auratus (Goldfish)	-	-	0.5 0.3 1.3	Leuven et al. 2011 Ford and Beitinger 2005 Ford and Beitinger 2005
Carassius gibelio (Prussian Carp)	-	-	0.5	Leuven et al. 2011
Channa argus (Northern Snakehead)	-	-	0	Okada 1960
Ctenopharyngodon idella (Grass Carp)	-	-	0.5	Leuven et al. 2011
Cyprinella lutrensis (Red Shiner)	-	-	-	-
Cyprinus carpio (Common Carp)	-	-	3 3	Leuven et al. 2011 Froese and Pauly 2017a
Esox lucius (Northern Pike)	0.1	Casselman 1978	-	-
Gambusia affinis (Western Mosquitofish)	2.7 3	Otto 1973 Otto 1973	3	Pyke 2005
Hemichromis letourneuxi (African Jewelfish)	9.1–13.3	Schofield et al. 2009	10.8–12.5	Schofield et al. 2009
Ictalurus punctatus (Channel Catfish)	0 2.5 6 4.7	Hart 1952 Hart 1952 Hart 1952 Hart 1952	2.7 6.5 9.8	Currie et al. 1997 Currie et al. 1997 Currie et al. 1997
Lepomis gibbosus (Pumpkinseed)	8.5 5 1.1–6.4	Schneider et al. 1975 Schneider et al. 1975 Evans 1977	1.7 4.1 8.7 12.1	Becker et al. 1977 Becker et al. 1977 Becker et al. 1977 Becker et al. 1977
Lepomis macrochirus (Bluegill)	3 5 7 11	EPA 1974 EPA 1974 EPA 1974 EPA 1974	-	-
Leuciscus idus (Ide/Orfe)	-	-	4	Leuven et al. 2011
Micropterus dolomieu (Smallmouth Bass)	2–10	EPA 1974	-	-

Micropterus salmoides (Largemouth Bass)	5.5 11.8 5.2 7 10.5	Hart 1952 Hart 1952 Hart 1952 Hart 1952 Hart 1952	3.2	Currie et al. 1997
Misgurnus anguillicaudatus (Japanese Weatherfish)	-	-	-1.8	Urquhart and Koetsier 2014
Neogobius melanostomus (Round Goby)	-1	Fuller et al. 2018	4	Leuven et al. 2011
Oncorhynchus mykiss (Rainbow Trout)	0.5 1.4 3.3	Becker et al. 1977 Becker et al. 1977 Becker et al. 1977	0 0.7 2.1 0.2 1.5 0.1 1.2 1.3 0.9	Currie et al. 1997 Becker et al. 1977 Becker et al. 1977 Becker et al. 1977 Becker et al. 1977 Becker et al. 1977 Becker et al. 1977 Becker et al. 1977 Becker et al. 1977
Oreochromis niloticus (Nile Tilapia)	8 8 5–13 6.2 8.2	Henson et al. 2018 El-Sayed et al. 1996 El-Sayed et al. 1996 Shafland and Pestrak 1982 Sifa et al. 2002	-	-
Perca flavescens (Yellow Perch)	1.1 3.7	Brown 1974 Brown 1974	-	-
Pimephales promelas (Fathead Minnow)	-	-	5.9	Heath et al. 1994
Poecilia latipinna (Sailfin Molly)	-	-	6.8 7.9 8.6 -	Yanar et al. 2019 Yanar et al. 2019 Yanar et al. 2019 -
Proterorhinus semilunaris (Freshwater Tubenose Goby)	-	-	4	Leuven et al.2011
Pseudorasbora parva (Stone Moroko)	-	-	5	Leuven et al. 2011
Sander lucioperca (Zander)	-0.6	Frisk et al. 2012	-	-
Sander vitreus (Walleye)	2.0–7.0	EPA 1974	-	-
Scardinius erythrophthalmus (Rudd)	-	-	2	Leuven et al. 2011
Silurus glanis (Wels Catfish)	13–14	Nienhuis 2016	-	-
Tinca tinca (Tench)			4	Leuven et al. 2011

Table A5. Lower thermal tolerance (LTT, °C) and overwintering ability (OA) for the identified species. Species are only included if data were verifiable and temperatures are reported in degrees Celsius (°C). Data is included as reported in the cited reference. A dash (-) indicates information not available.

Species	LTT	LTT Reference	OA	OA reference
Alosa pseudoharengus (Alewife)	3	Neves 1981	-	-
Channa argus (Northern snakehead)	5	Lapointe et al. 2010	-	-
Cyprinella lutrensis (Red shiner)	-	-	Likely	Nico et al. 2018
Gymnocephalus cernuus (Ruffe)	-	-	Likely	Kolar and Lodge 2002
Hemichromis letourneuxi (African Jewelfish)	-	-	Unlikely	Schofield et al. 2009
Hypophthalmichthys molitrix (Silver carp)	-	-	Likely	Kolar et al. 2005
Hypophthalmichthys nobilis (Bighead carp)	2	Kolar et al. 2005	-	-
Morone americana (White perch)	-	-	-	-
Morone chrysops (White bass)	-	-	Likely	Robitaille et al. 2011
Mylopharyngodon piceus (Black carp)	0.5	Schofield et al. 2005	-	-
Neogobius melanostomus (Round goby)	-	-	Likely	Evans and Loftus 1987
Osmerus mordax (Rainbow smelt)	-	-	Likely	Evans and Loftus 1987
Petromyzon marinus (Sea lamprey)	0	Hansen et al. 2016	-	-
Proterorhinus semilunaris (Freshwater tubenose goby)	-	-	Likely	Kolar and Lodge 2002
Pseudorasbora parva (Stone moroko)	2	CABI 2018	-	-
Rhodeus sericeus (Amur bitterling)	12	Souchon and Tissot 2012	-	-
Sander lucioperca (Zander)	-	-	Likely	Kerr 2014a, Larsen and Berg 2014

Table A6. Thermal and reproductive guilds, and geographic origin for 68 fish species identified to be potentially invasive to (or within) the Prairie region (nd = no data).

Scientific name	Common name	Thermal guild	Reproductive guild	Geographic origin
Acipenser medirostris	Green Sturgeon	cool/cold	A1	North America
Alosa pseudoharengus	Alewife	cool	A1	North America
Ameiurus melas	Black Bullhead	warm/cool	B2	North America
Ameiurus natalis	Yellow Bullhead	warm	B2	North America
Ameiurus nebulosus	Brown Bullhead	warm	B2	North America
Amia calva	Bowfin	warm	B2	North America
Amphilophus citrinellus	Midas Cichlid	warm	B2	Central America
Astronotus ocellatus	Oscar	warm	B2	South America
Atractosteus spatula	Alligator Gar	nd	A1	North America
Carassius auratus	Goldfish	warm	A1	Asia
Carassius gibelio	Prussian Carp	warm	A1	Eurasia
Channa argus	Northern Snakehead	warm	B1	Asia
Channa maculata	Blotched Snakehead	warm	B1	Asia
Channa marulius	Bullseye Snakehead	warm	B1	Asia
Channa micropeltes	Giant Snakehead	warm	B1	Asia
Ctenopharyngodon idella	Grass Carp	warm	A1	Asia
Cyprinella lutrensis	Red Shiner	warm	A2	North America
Cyprinus carpio	Common Carp	warm	A1	Eurasia
Esox lucius	Northern Pike	cool	A1	Circumpolar
Esox masquinongy	Muskellunge	warm	A1	North America
Gambusia affinis	Western Mosquitofish	warm	C2	North America
Gymnocephalus cernuus	Eurasian Ruffe	cool	A1	Europe
Hemichromis letourneuxi	African Jewelfish	warm	B2	Africa
Hypophthalmichthys molitrix	Silver Carp	warm	A1	Asia
Hypophthalmichthys nobilis	Bighead Carp	warm	A1	Asia
Ictalurus punctatus	Channel Catfish	warm	B2	North America
Ictiobus cyprinellus	Bigmouth Buffalo	warm	A1	North America
Lepomis cyanellus	Green Sunfish	warm	B2	North America
Lepomis gibbosus	Pumpkinseed	warm	B2	North America
Lepomis macrochirus	Bluegill	warm	B2	North America
Leuciscus idus	Orfe or Ide	cold	A1	Eurasia
Micropterus dolomieu	Smallmouth Bass	cool	B2	North America
Micropterus salmoides	Largemouth Bass	warm	B2	North America

Misgurnus anguillicaudatus	Japanese Weatherfish	warm	A1	Asia
Morone americana	White Perch	warm	A1	North America
Morone chrysops	White Bass	warm	A1	North America
Mylopharyngodon piceus	Black Carp	warm	A1	Asia
Neogobius melanostomus	Round Goby	warm	B1	Eurasia
Notropis hudsonius	Spottail Shiner	warm/cool	nd	North America
Noturus gyrinus	Tadpole Madtom	nd	nd	North America
Oncorhynchus aguabonita	Golden Trout	nd	A2	North America
Oncorhynchus mykiss	Rainbow Trout	cool	A2	North America
Oreochromis niloticus	Nile Tilapia	warm	C1	Africa
Osmerus mordax	Rainbow Smelt	cold	A1	North America
Perca flavescens	Yellow Perch	warm	A1	North America
Percopsis omiscomaycus	Trout Perch	cold	A1	North America
Petromyzon marinus	Sea Lamprey	cold	A2	Circumpolar
Phractocephalus hemioliopterus	Redtail Catfish	warm	A1	South America
Pimephales promelas	Fathead Minnow	warm	B2	North America
Platygobio gracilis	Flathead Chub	nd	A1	North America
Poecilia latipinna	Sailfin Molly	warm	C2	North America
Pomoxis annularis	White Crappie	warm/cool	B2	North America
Pomoxis nigromaculatus	Black Crappie	warm/cool	B2	North America
Proterorhinus semilunaris	Tubernose Goby	cold	B2	Europe
Pseudorasbora parva	Stone Moroko	cold	A2	Asia
Pygocentrus nattereri	Red-bellied Piranha	warm	B2	South America
Rhodeus sericeus	Amur Bitterling	cool	A2	Asia
Salmo letnica	Ohrid Trout	nd	A2	Europe
Salmo trutta	Brown Trout	cool/cold	A2	Eurasia
Salvelinus fontinalis	Brook Trout	cool/cold	A2	North America
Sander lucioperca	Zander	cool	B2	Eurasia
Sander vitreus	Walleye	cool	A1	North America
Scardinius erythrophthalmus	Rudd	cold	A1	Eurasia
Serrasalmus rhombeus	Black Pirahna	warm	A1	South America
Siluris glanis	Wels Catfish	cool	B2	Eurasia
Synodontis ocellifer	Large-spot Catfish	warm	A1	Africa
Tinca tinca	Tench	cool	A1	Eurasia
Umbra limi	Central Mudminnow	warm/cool	B1	North America

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