

A Biological Synopsis of Black Crappie (*Pomoxis nigromaculatus*)

Jennifer R. Powell, Marc-André Plourde

Fisheries and Oceans Canada
Gulf Fisheries Centre
343 University Avenue
Moncton, New Brunswick
E1C 9B6

2025

**Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3256**



Fisheries and Oceans
Canada

Pêches et Océans
Canada

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426 - 1550 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 900 de cette série ont été publiés à titre de Manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme Manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de Rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de Rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3256

2025

A BIOLOGICAL SYNOPSIS OF BLACK CRAPPIE (*POMOXIS NIGROMACULATUS*)

By

Jennifer R. Powell, Marc-André Plourde

Fisheries and Oceans Canada
Gulf Fisheries Centre
343 University Avenue
Moncton, N.B.
E1C 9B6

© His Majesty the King in Right of Canada, as represented by the Minister of the Department of Fisheries and Oceans, 2025

Cat. No. Fs97-4/3256E-PDF ISBN 978-0-660-47024-5 ISSN 1488-5387
<https://doi.org/10.60825/0a8x-wj88>

Correct citation for this publication:

Powell, J.R., Plourde, M.-A. 2025. A Biological synopsis of Black Crappie (*Pomoxis nigromaculatus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 3256: viii + 59 p.
<https://doi.org/10.60825/0a8x-wj88>

TABLE OF CONTENTS

LIST OF TABLES	v
LIST OF FIGURES	v
ABSTRACT	vii
RÉSUMÉ	viii
1.0 INTRODUCTION.....	1
1.1 NAME, CLASSIFICATION AND IDENTIFIERS	1
1.2 DESCRIPTION	2
1.2.1 Taxonomy	6
2.0 DISTRIBUTION.....	6
2.1 GLOBAL NATIVE DISTRIBUTION	6
2.2 NATIVE DISTRIBUTION IN CANADA	6
2.3 NON-NATIVE DISTRIBUTION	7
2.3.1 Outside the United States and Canada	7
2.3.2 United States	8
2.3.3 Canada	8
2.4 MODES OF INVASION.....	9
2.4.1 Authorized introductions.....	9
2.4.2 Accidental live release	10
2.4.3 Illegal introductions	10
2.4.4 Escape from reservoirs and impoundments	11
2.4.5 Natural dispersal.....	11
3.0 BIOLOGY AND NATURAL HISTORY	12
3.1 LIFE CYCLE.....	12
3.2 AGE AND GROWTH	12
3.2.1 Standard growth and weight equations	17
3.3 REPRODUCTION.....	18
3.3.1 Spawning.....	18
3.3.2 Nests	20
3.4 FEEDING AND DIET.....	20
3.4.1 Diets	20
3.4.2 Feeding behavior	22
3.5 HABITAT REQUIREMENTS.....	23
3.5.1 General Habitat.....	23
3.5.2 Spawning Habitat.....	24
3.5.3 Habitat Suitability Index (HSI)	24
3.5.4 Habitat suitability in New Brunswick	24
3.6 SPECIES INTERACTIONS	27

3.7	BEHAVIOR AND MOVEMENT	32
3.7.1	General movement	32
3.7.2	Diel movement	32
3.7.3	Seasonal movement	32
3.7.4	Swimming speed	33
3.8	PHYSIOLOGICAL TOLERANCES	33
3.8.1	Turbidity	33
3.8.2	Temperature	34
3.8.3	Dissolved Oxygen	36
3.8.4	Salinity	36
3.8.5	pH	37
3.8.6	Water velocity	37
3.8.7	Interacting tolerances	37
3.9	DISEASES AND PARASITES	37
3.9.1	Viral hemorrhagic septicemia (VHS)	37
3.9.2	Parasites	39
3.9.3	Bacterial infections	39
3.9.4	Testicular Oocytes	40
3.9.5	Black Crappie Sarcoma (BCS)	40
4.0	USE BY HUMANS	40
4.1	RECREATIONAL FISHING	40
4.2	COMMERCIAL FISHING	40
4.3	AQUACULTURE	41
5.0	IMPACTS ASSOCIATED WITH INTRODUCTIONS	41
5.1	IMPACTS ON PLANKTON AND BENTHIC INVERTEBRATES	41
5.2	IMPACTS ON MUSSELS	42
5.3	IMPACTS ON FISH	43
5.3.1	Predation and competition	43
5.3.2	Hybridization	45
6.0	REFERENCES	50

LIST OF TABLES

Table 1. Larval Black Crappie characteristics.	5
Table 2. Effect of abiotic and biotic variables on growth, recruitment, and survival of Black Crappie.	13
Table 3. Description of variables used in Black Crappie Habitat Suitability Index model (Edwards et al. 1982).	25
Table 4. Habitat Suitability Index (HSI) model equations for riverine and lacustrine habitats. ...	27
Table 5. Summary of water velocities collected during benthic macroinvertebrate sampling between 2014–2017 in Saint John River in the vicinity of Mactaquac Generating Station (MGS) compared to Black Crappie tolerances.	30
Table 6. Summary of water quality parameters collected quarterly 2003–2015 in Saint John River in the vicinity of Mactaquac Generating Station (MGS) compared to Black Crappie tolerances.	31
Table 7. Distribution and conservation status of mussel species known to utilise Black Crappie as a host.	43
Table 8. Mussel species presence potential in Saint John River and their potential to use Black Crappie as a host.	43
Table 9. Fish species recorded in the Saint John River and their potential as Black Crappie prey or predator.	46

LIST OF FIGURES

Figure 1. Adult Black Crappie. Photo: Jennifer Powell.....	3
Figure 2. Juvenile Black Crappie. Source: Auer 1982, original illustration Wang and Kernehan 1979.....	4
Figure 3. Larval Black Crappie development. Source: Swing and McGowan (1987).	4
Figure 4. Native and introduced distribution of Black Crappie in the United States. Source: USGS 2022	7
Figure 5. A) Distribution of Black Crappie in British Columbia. Black Crappie are not native to the province. Source: McPhail 2021. B) Native (blue) and introduced (red) distribution of Black Crappie in Central Canada. Source: Mandrak et al. in press.	7
Figure 6. Suspected migration path of Black Crappie from Virginia Lake after removal of fish screen from outlet, Maine, 1945 – 1952. Created with information from: DeRoche and Foye (1954).	11
Figure 7. Suitability index graphs for variables 1-9 for Black Crappie Habitat Suitability Index (Edwards et al. 1984). R = Rivers, L = Lakes. 1, % cover during mid-summer within pools, overflow areas, and backwaters (R) and the littoral zone (L). 2, Average current velocity in pools and backwater areas during average summer flow. 3, Most suitable water temperature within the epilimnion (L) or in pools and backwaters (R) during midsummer (adult). 4, Most suitable water temperature within the epilimnion (L) or in pools and backwaters (R) during midsummer (juvenile).	29
Figure 8. Suitability index graphs for variables 10-15 for Black Crappie Habitat Suitability Index (Edwards et al. 1984). R = Rivers, L = Lakes. 1, Average water temperature within littoral areas (L) or in pools and backwaters (R) during midsummer (fry). 2, Average water temperature within littoral areas (L) or backwaters (R) during spawning (embryo). 3, Minimum DO within	

temperature strata selected above (V8, V9, V10) during midsummer (fry-adult). 4, Minimum DO within littoral areas (L) or backwaters (R) during spawning (embryo, fry)	30
Figure 9. Geographic distribution of viral haemorrhagic septicaemia virus (VHSV). Source: Garver and Hawley 2021.	38

ABSTRACT

Powell, J.R., Plourde, M.-A. 2025. A Biological synopsis of Black Crappie (*Pomoxis nigromaculatus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 3256: viii + 59 p.

<https://doi.org/10.60825/0a8x-wj88>

This synopsis reviews biological information on the Black Crappie (*Pomoxis nigromaculatus*) in support of a risk assessment evaluating the impacts of a potential range expansion in Canada with particular focus on its potential effects on the Saint John River watershed in New Brunswick. Due to widespread introductions throughout the United States for recreational fishing starting in the 1800s, Black Crappie's native distribution is poorly known but is thought to be eastern-central North America. It is now almost ubiquitous in the United States and is also found in British Columbia, Manitoba, Ontario, Québec, and New Brunswick. Black Crappie prefer clear, slow-moving, heavily vegetated waters, but can persist under a wide variety of conditions. Young Black Crappie are planktivorous, adding invertebrates, and eventually fish as they grow. While they do show food preferences as a species, Black Crappie are opportunistic and will often feed on whatever is readily available. Their varied diet at different life stages means introduced young Black Crappie can cause impacts on herbivorous fish species through competition for food resources, while older fish can cause impacts through predation. In New Brunswick, Black Crappie are most likely to negatively impact Yellow Perch (diet overlap and strong predation) and White Perch (diet overlap).

RÉSUMÉ

Powell, J.R., Plourde, M.-A. 2025. A Biological synopsis of Black Crappie (*Pomoxis nigromaculatus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 3256: viii + 59 p.
<https://doi.org/10.60825/0a8x-wj88>

Le présent synopsis examine les données biologiques sur la marigane noire (*Pomoxis nigromaculatus*) pour appuyer une évaluation des risques portant sur les effets de l'expansion de son aire de répartition au Canada mais avec une attention particulière sur les effets potentiels dans le bassin versant de la Rivières Saint-Jean au Nouveau Brunswick. A cause de l'introduction généralisée aux États-Unis pour la pêche récréative qui débuta dans les années 1800, la distribution naturelle de la marigane noire est très peu connue, mais on pense qu'elle se limite à la portion centrale de l'est de l'Amérique du Nord. La marigane noire est aujourd'hui pratiquement omniprésente partout aux États-Unis et est aussi retrouvée en Colombie Britannique, au Manitoba, en Ontario, au Québec et au Nouveau Brunswick. La marigane noire préfère les eaux lentes avec une végétation dense mais peut persister dans des conditions très variées. Les jeunes mariganes noires sont planctivores, et ajoutent des invertébrés et éventuellement du poisson dans leur nutrition à mesure qu'ils grandissent. Bien qu'elle démontre des préférences en terme de nourriture, la marigane noire est opportuniste et se nourrit souvent de ce qui est facilement disponible. Leur nutrition variée à différents stades de leur vie signifie que l'introduction de la marigane noire juvenile peut causer des impacts sur des espèces de poissons herbivores par l'entremise de la compétition pour de la nourriture, tandis que des poissons plus vieux peuvent causer des impacts par la prédation. Au Nouveau Brunswick, la marigane noire aurait fort probablement un impact négatif sur la perchaude (doré jaune) (chevauchement de régime et prédation forte) et le baret (chevauchement de régime).

1.0 INTRODUCTION

Black Crappie (*Pomoxis nigromaculatus*) is a North American freshwater fish of the Sunfish family (Centrarchidae) that is ubiquitous in the United States but has a limited distribution within Canada. Highly prized as a panfish and, to a lesser degree, sportfish, Black Crappie are an important component of recreational fisheries within the United States and is often popular in Canadian recreational fisheries where they occur.

Black Crappie populations in Canada are at the northern edge of their range and as the effects of climate change progress, there is potential for Black Crappie to expand further into Canadian waters. In Ontario over the last 40 years, many lakes have shifted from being dominated by cyprinids (i.e. carps and minnows) to being dominated by centrarchids, a shift linked to climate change (Finigan et al. 2018). Hauger (2020) stated that Black Crappie's "high tolerance to water temperature changes, high fecundity, and diet variability make them great candidates for range expansion". As most Black Crappie introductions have been intentional by fisheries managers, their natural dispersal ability has not been well documented. Not generally known as an aggressive aquatic invader, they nevertheless persist in most waterbodies where they are introduced (Lucas 2002) and can quickly overpopulate small waterbodies (Culpepper and Allen 2016).

This report provides a biological synopsis for Black Crappie, with particular focus on its potential impacts on New Brunswick and the Saint John River basin, the structure and contents of which is based on the "*National Detailed-Level Risk Assessment Guidelines: Assessing the Biological Risk of Aquatic Invasive Species in Canada*" (Mandrak et al. 2011).

1.1 NAME, CLASSIFICATION AND IDENTIFIERS

Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Centrarchiformes
Family: Centrarchidae
Subfamily: Centrarchinae
Genus: Pomoxis
Species: *nigromaculatus*

Scientific name: *Pomoxis nigromaculatus* Lesueur (1829)

Common names (English): Black Crappie, crappie, crawpie, croppie, crappé, calico bass, grass bass, moonfish, Oswego bass, shiner, speckled bass, speck, strawberry bass, papermouth, speckled perch, white perch, crappie bass

Common name (French): marigane noire, sacalait (Louisiana)

Common name (Spanish): mojarra negra, robaleta prieta

The genus name *Pomoxis* is derived from Greek and means 'sharp [operculum] cover', while *nigromaculatus* means 'black-spotted' in reference to the fish's general coloration (Froese and Torres 2022). The common name 'crappie' is derived from the French Canadian 'crapet' (Merriam-Webster 2022), which refers to sunfishes in general (Government of Quebec 2012).

1.2 DESCRIPTION

Members of the centrachid family often go by the name sunfishes, so named for the often colorful appearance of many of the family's species. Sunfishes are laterally-compressed and have spiny- and soft-rayed portions to their dorsal fin which are narrowly to fully connected, often resembling one fin (Page and Burr 2011; Hubbs et al. 2004). This distinguishes them from the similar perch (Percidae) which mostly have two distinct dorsal fins. The temperate basses (Moronidae) have either two distinct, or two narrowly connected dorsal fins, but also have a point or spine on their opercle flap, separating them from the sunfishes (Hubbs et al. 2004).

In Canada, the sunfish family can be broken down into four sub-groups: 1) sunfish (*Lepomis* spp.), 2) bass (Largemouth Bass (*Micropterus nigricans*) and Smallmouth Bass (*Micropterus dolomieu*)), 3) crappies (*Pomoxis* spp.), and 4) Rock Bass (*Ambloplites rupestris*). The basses have a much shallower, elongated profile (body depth 1/3 standard length) than the other sunfishes (about half standard length) (Hubbs et al. 2004) and basses and sunfishes only have 3 anal spines compared to 6 in the crappies and Rock Bass (Page and Burr 2011). Rock Bass have 11 or 12 dorsal spines and 6 branchiostegal rays, while crappies have 6 to 8 (Hubbs et al. 2004, Auer 1982).

The crappies are represented by two species of the genus *Pomoxis*, Black Crappie and White Crappie (*Pomoxis annularis*). Black and White Crappie share many physical characteristics and can be difficult to tell apart. Both are deep bodied, extremely laterally compressed, have a long predorsal region with a sharp dip over the eye, a large mouth that extends under the eye, are grey-green above, and their dorsal, caudal, and anal fins are dark with numerous light spots (Page and Burr 2011, Scott and Crossman 1973). However, they do differ in several ways. Black Crappie have 7 or 8 dorsal spines, the length of the dorsal fin base is about equal to the distance from the dorsal origin to the eye, and its body is darkly spotted and/or has wavy black bars, but lacks distinct vertical bars (Fig. 1) (Page and Burr 2011, Hubbs et al. 2004, Scott and Crossman 1973). White Crappie have 6 (rarely 7) dorsal spines, the length of the dorsal fin base is much less than the distance from the dorsal origin to the eye, and its body has 5 to 8 regularly spaced vertical bands (Page and Burr 2011, Hubbs et al. 2004). As well, Black Crappie have deeper bodies; slightly greater pelvic fin length (Porreca et al. 2020); shorter, deeper caudal peduncles (Porreca et al. 2020, Auer 1982, Scott and Crossman 1973); and are less elongate (Scott and Crossman 1973) when compared to White Crappie.

Black and White Crappie are known to hybridize in the wild (Bolnick 2009, Hubbs et al. 2004, Auer 1982). Hybrid *Pomoxis* look nearly indistinguishable from Black Crappie and molecular rather than morphological techniques are needed to accurately identify them (Bolnick 2009).

In Canada, adult Black Crappie are usually 178–254 mm in length (Scott and Crossman 1973), with an average maximum size across its range of 390 mm (Cooke and Philipp 2009), and the maximum recorded size around 559 mm (Edwards et al. 1982). Although the sexes are similar in appearance, during breeding males become darker and more iridescent, particularly on the head, and do not develop breeding tubercles (Scott and Crossman 1973). Juvenile crappie in the Great Lakes basin typically range between 16–27 mm in length (Auer 1982). When compared to adults, juveniles tend to have less pigmentation on the tail, dorsal, and anal fins (CABI 2022); a less pronounced dip over the eye; and a shallower body depth (30–33% of total length) (Auer 1982) (Fig. 2). Newly hatched larvae and yolk-sac larvae range between 1.2–4.0 mm (Auer 1982) with larvae absorbing yolk material before reaching 5.0 mm (Swing and McGowan 1987). Illustrations of larval Black Crappie development are provided in Figure 3 and detailed descriptions of the characteristics of yolk-sac (2–4 mm), 3–6 mm, and 6–18 mm larvae are provided in Table 1.

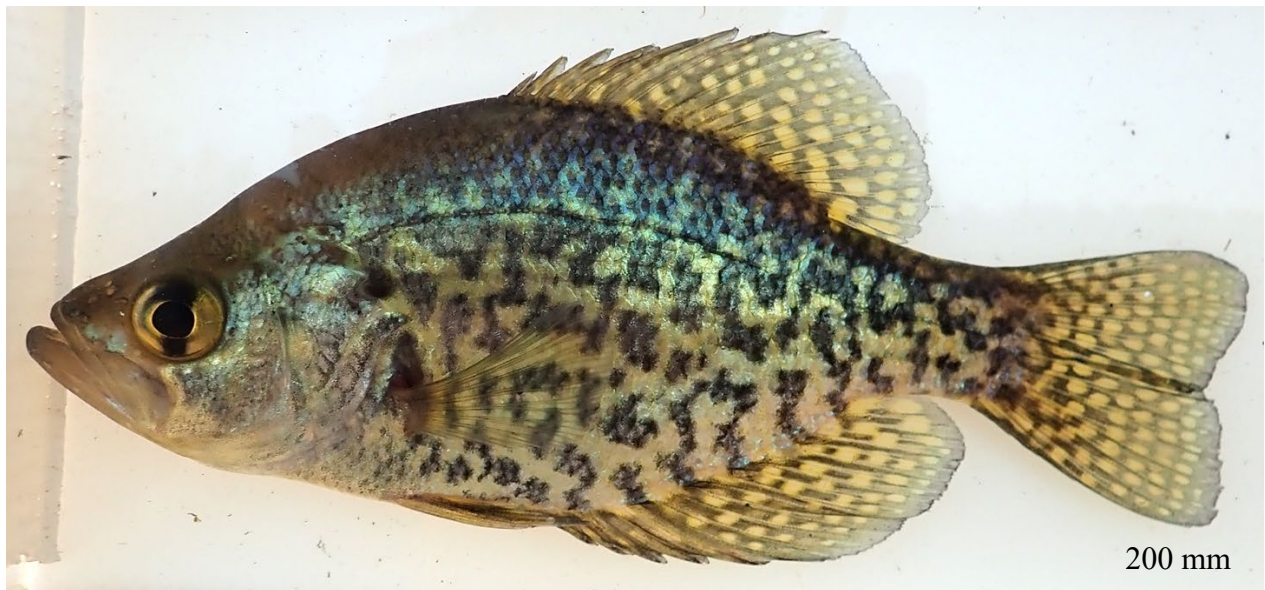


Figure 1. Adult Black Crappie. Photo: Jennifer Powell

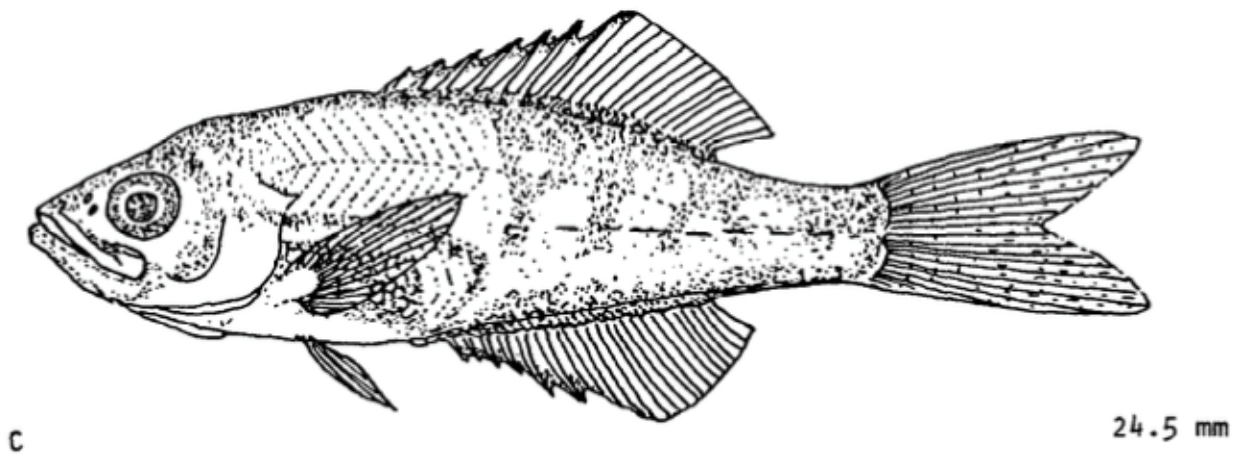


Figure 2. Juvenile Black Crappie. Source: Auer 1982, original illustration Wang and Kernehan 1979.

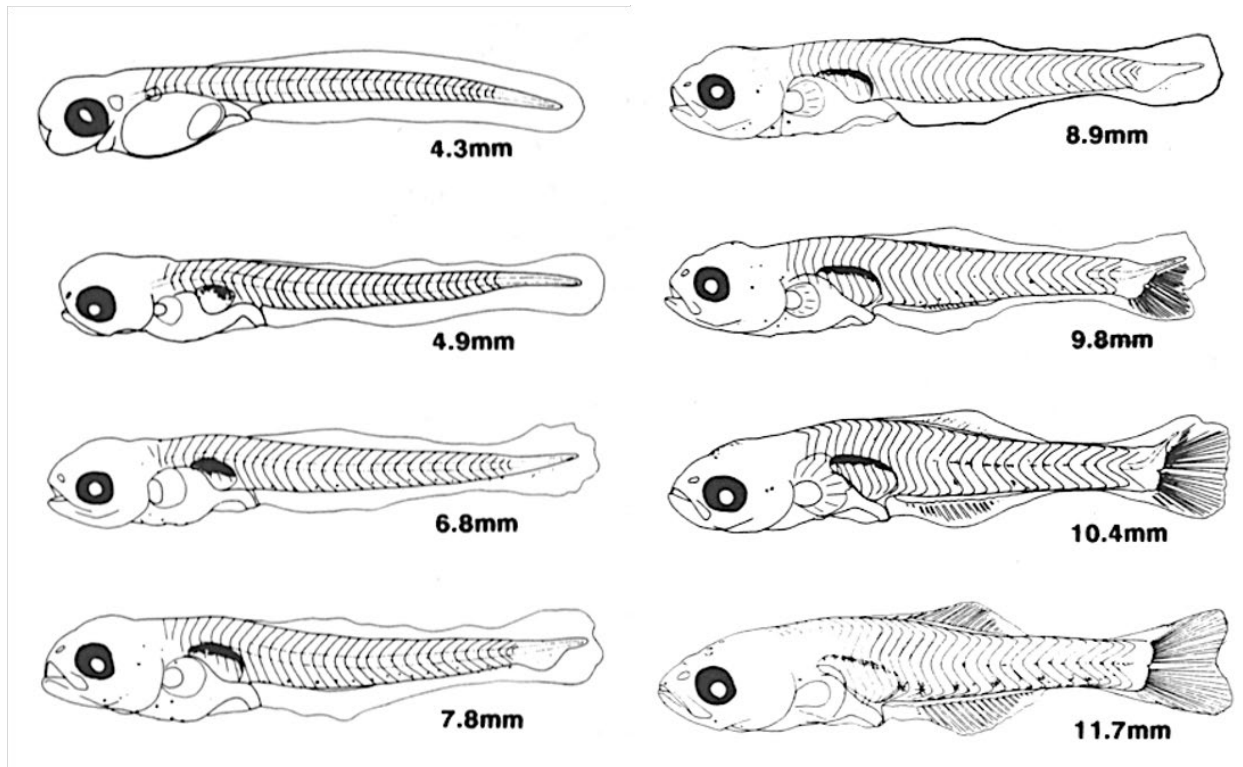


Figure 3. Larval Black Crappie development. Source: Swing and McGowan (1987).

Table 1. Larval Black Crappie characteristics.

Trait	Yolk-sac Larvae	Larvae	
	2–4 mm (newly hatched 2.3)	3–6 mm	6–18 mm
Myomeres	• 29 to 31 (10 to 13 + 19-23)	• 31 to 35 (10 to 13 + 19 to 23)	• 31 (11 to 14 + 18 to 21) at 6 to 16 mm
Morphometry (as % TL)	• Distance from eye to swim bladder less than 15% TL	• Preanal length 36 to 37 • Head length 13 to 16 • Greatest body depth 13 to 16 • Eye diameter 6 to 7	• Preanal length 39 to 41 -Head length 17 to 19 -Greatest body depth 15 to 16 -Eye diameter 5 to 6 (7.5 to 8.0 mm) • Preanal length 40 to 43 -Head length 20 to 23 -Greatest body depth 17 to 20 -Eye diameter 7 (10.5 to 11.0 mm) • Preanal length 39 to 41 -Head length 23 to 25 -Body depth 19 to 22 -Eye diameter 7 to 8 (13.5 to 14.0 mm) -Length of dorsal fin greater than eye to dorsal fin distance
Morphology	• Gut coiled (<3 mm) • Swim bladder formed (3.4 to 3.8 mm) • Oil globule located in middle or anterior portion of yolk sac (3.5 to 8 mm)	• Yolk absorbed (3.5 to 3.9 mm)	• Incipient caudal fin rays (7 to 9.0 mm) • Urostyle upturned (8 mm) • Rays developing in soft dorsal and anal fins (9.5 to 10.0 mm) • First spines in dorsal and anal fins (11.5 to 11.9 mm) • Pelvic buds forming (11 mm) • Incipient rays in pectoral and pelvic fins (14 mm) • Dorsal fin with 7 spines (16 mm and larger) • Scales appear (mean length 17.7 mm)
Pigmentation			• Melanophores on dorsum of swim bladder, sides of head, anterior part of stomach and along mid ventral line • Subsurface spots on dorsal just posterior to head –Melanophores on both sides of myomeres below midlateral myoseptum • In some specimens, pigment in a ventral-lateral line (8mm) • Melanophores on caudal fin • Ventro-lateral row of pigment distinct • A double ventral row of pigment along anal fin, lateral row on posterior half of body, ventro-lateral row less conspicuous • Melanophores on top and sides of head, lower and upper jaw and lateral aspect of stomach (11 to 14 mm) • A double dorsal row of pigment along dorsal fin • Melanophores on anal and dorsal fins in some specimens (14 to 17 mm)

Source: Auer 1982

1.2.1 Taxonomy

The order Centrarchiformes (included in Perciformes until 2012 (Near et al. 2012)), contains 20 globally distributed families (Fricke et al. 2020). The family Centrarchidae, or Sunfish family, is native to North America, contains 8 genera and 38 species (Fricke et al. 2020) and is characterized by a laterally-compressed body and a dorsal fin composed of spiny and soft rayed sections which are narrowly to fully connected, often resembling one fin (Page and Burr 2011, Hubbs et al. 2004).

The subfamily Centrarchinae encompasses all genera of sunfishes except *Lepomis* and *Micropterus* (Fricke et al. 2020). In Canada, the Centrarchinae is represented by Black and White Crappie and Rock Bass. The genus *Pomoxis* is only represented by Black and White Crappie, which are described in detail in Section 1.2.

2.0 DISTRIBUTION

2.1 GLOBAL NATIVE DISTRIBUTION

Black Crappie were originally restricted to the freshwaters of the eastern United States, and small portions of the southern edge of Canada. The exact extent of the native distribution of Black Crappie is unknown due to widespread introductions (Page and Burr 2011) for recreation throughout the continental United States and parts of Canada from the 1800's onward (Carlander 1977, Carl and Guiguet 1958, Rawson and Ruttan 1952). Its original range is believed to have been largely restricted to the lowlands of the eastern United States, extending from the Red River and Mississippi River basin in the northwest and western portions of its range, through the Great Lakes and Saint-Lawrence River basins in the north, the Atlantic slope region of the eastern United States (Virginia and south) in the east, and along the Gulf of Mexico between Florida and Texas in the south (USGS 2022, Page and Burr 2011, Hubbs et al. 2004, Carlander 1977, Scott and Crossman 1973) (Fig. 4).

2.2 NATIVE DISTRIBUTION IN CANADA

Within Canada, the native distribution of Black Crappie is thought to have been originally restricted to Ontario and Québec (Fig. 5). In the east, it ranged from the Saint Lawrence and its tributaries, to brackish waters near Rivière Ouelle, the Richelieu-Champlain system, and the Ottawa River. It ranged across southern and central Ontario north to a line from Temiskaming to Sault Ste. Marie and was also present in the Great Lakes with the exception of Lake Superior (Mandrak et al. in press, Scott and Crossman 1973).

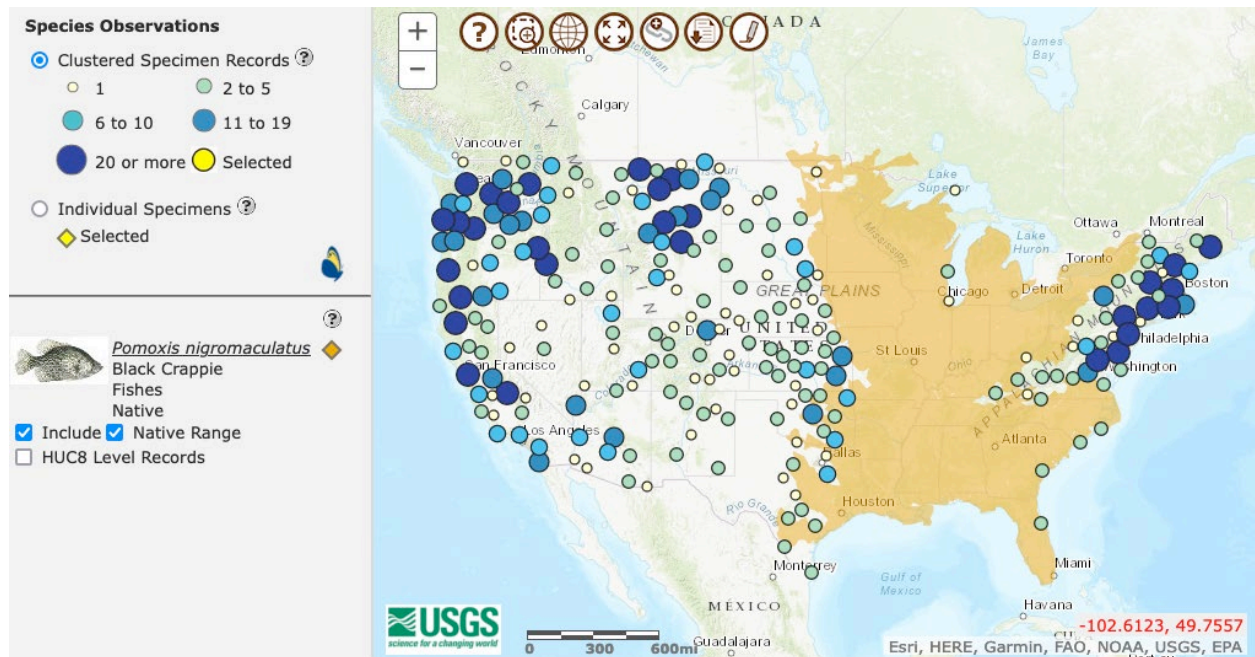


Figure 4. Native and introduced distribution of Black Crappie in the United States. Source: USGS 2022

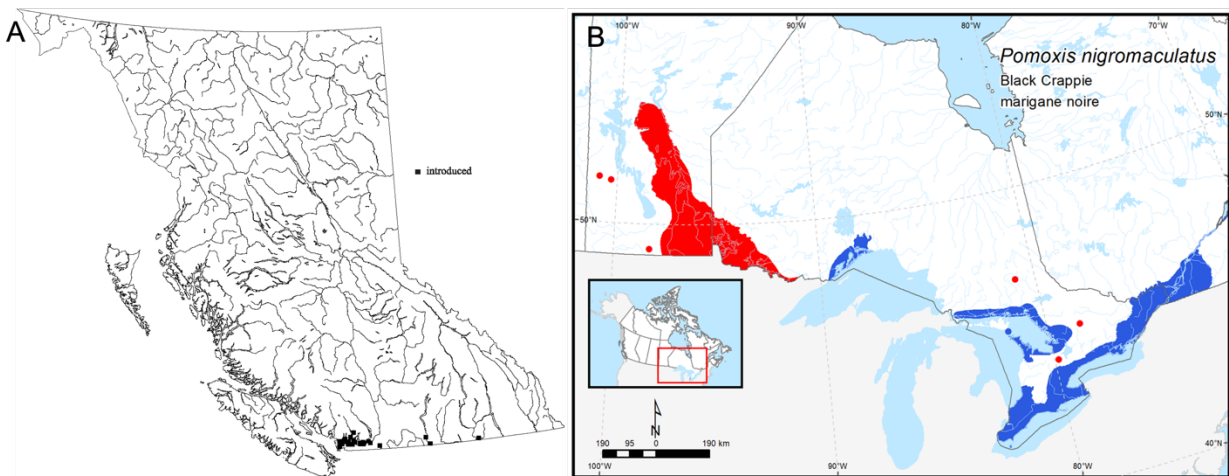


Figure 5. A) Distribution of Black Crappie in British Columbia. Black Crappie are not native to the province. Source: McPhail 2021. B) Native (blue) and introduced (red) distribution of Black Crappie in Central Canada. Source: Mandrak et al. in press.

2.3 NON-NATIVE DISTRIBUTION

2.3.1 Outside the United States and Canada

Outside of Canada and the United States, there are records of Black Crappie introductions in México, Panamá, Japan, Morocco, China (Froese and Torres 2022), and Guatemala (STRI 2022, UVG 2021). Black Crappie was introduced to Japan and Morocco for cultivation in the 1920's and 1960's respectively, but did not become established and no longer appear to be under

cultivation (FAO 2022, Froese and Torres 2022). Records exist for Black Crappie introduction into China in 1989, but it is unknown if they became established (Froese and Torres 2022).

In México, Black Crappie was first reported in the Colorado River in the state of Baja California in the 1950's (Frale 2019, Follett 1960), where it is suspected to have migrated from artificial reservoir and irrigation systems in neighbouring Arizona and California, or having been imported for aquaculture (Ruiz-Campos et al. 2014, Welcome 1988). Since that time, specimens have been collected from other locations within Baja California (Ruiz-Campos et al. 2014), Yaqui River in Sonora state (Ruiz-Campos 2021, Varela-Romero 2021, Ruiz-Campos et al. 2014), and from Durango state (Macías-García 2021). There are also three records from 2020 and 2021 on iNaturalist from Baja California, Durango, and further south in San Luis Potosí (iNaturalist 2022).

There are several specimen records of Black Crappie in Lake Atitlan in Guatemala, collected in 1996, 1998, and 2005 (STRI 2022, UVG 2021), but no details on how they were introduced to the lake were provided. Black Crappie are known to have been introduced to Panamá (Froese and Torres 2022) and is on the aquatic species list for the country (STRI 2022), but no other information on this introduction or its current distribution in the country was located.

2.3.2 United States

Black Crappie was widely introduced throughout the continental US starting in the 1800s onward and is now present in almost all US states (Carlander 1977, Carl and Guiguet 1958, Rawson and Ruttan 1952) (Fig. 4). In some areas, it is believed Black Crappie distribution cannot expand further due to having been stocked in every area where it can survive (Riso 2011).

2.3.3 Canada

Although originally thought to be restricted to Ontario and parts of Québec, Black Crappie can now also be found in Manitoba, British Columbia, and most recently, New Brunswick, with its range within Ontario having expanded over the years (Fig. 5).

Black Crappie were first introduced to Washington State in the United States in the 1890s and from there were introduced into British Columbia (Quinn and Paukert 2009). Black Crappie were first recorded in British Columbia in Hatzic Lake in 1933 (Carl and Guiguet 1958) and have since spread through systems connected to the Lower Fraser River (McPhail and McPhail 2007, Carl and Guiguet 1958), and is also found in the Okanagan and Columbia rivers near the border with the United States (Fig. 5a) (McPhail and McPhail 2007).

Attempts were made to introduce White Crappie and other sunfishes into Saskatchewan in the 1930's without success (Rawson and Ruttan 1952). Although some records show Black Crappie as being present in Saskatchewan; (NatureServe 2022b, SCDC 2021), the records are based on the previous introduction efforts, and no current populations of the fish are known in the province (J. Keith, personal communication, March 11, 2022).

Historically, the Black Crappie's most northern population was found in central southern Manitoba in the Red and Assiniboine rivers, stretching east into Lake of the Woods in western Ontario (Scott and Crossman 1973). However, in the mid-1940s, Black Crappie were accidentally introduced into the waterbodies of Whiteshell Provincial Park in southeastern Manitoba when individuals were inadvertently included while stocking Smallmouth Bass (Hauger 2020). However, the population's numbers remained low and the range small until the last 10 to 15 years when Black Crappie have begun to expand and increase in abundance in the park (Hauger 2020). Black Crappie has now spread through the Winnipeg River system and into Lake Winnipeg and may no longer be present in the Assiniboine River (Langhorne et al. 2001) (Fig. 5).

In Ontario, the range of Black Crappie has expanded over the years to include Lake Superior, the result of spread from introductions to a nearby lake (Scott and Crossman 1973), and has been introduced in a few locations in central Ontario (Mandrak et al. in press) (Fig. 5).

In February 2019, Black Crappie were reported to be present in Big Lake, a 3.4 ha lake near Millville, New Brunswick (McAlpine et al. 2020). Big Lake is at the headwaters of the Nackawick Stream watershed, approximately 25 km upstream of its confluence with the Saint John River, in which Black Crappie is not known to be present. Fish community assessment in the Saint-John River Mactaquac Reservoir, where Nackawick stream sheds, yielded no observation of Black Crappie in 2016-2017 (Gautreau et al. 2018). Further assessment of Big Lake in June 2021 confirmed presence of over 200 Black Crappie of different age classes, indicating a reproducing population (Plourde 2021, unpublished data).

2.4 MODES OF INVASION

Several modes of invasion have been documented for Black Crappie introductions, including: authorized introductions, accidental live release, illegal introductions, escape from reservoirs and impoundments, and natural dispersal.

2.4.1 Authorized introductions

Intentional stocking for recreational fishing and, to a lesser extent, aquaculture has historically been the primary method of introduction for Black Crappie. Most introductions of Black Crappie in the United States were carried out by federal and state fisheries management bodies who stocked them widely and subsequently managed their populations for recreational fishing (Riso 2011). In the 2nd half of the 20th century, Black Crappie expansion continued alongside a boom in reservoir building, where they were extensively stocked (Quinn and Paukert 2009).

Attempts have been made to introduce Black Crappie outside of the United States for recreation (Canada) and aquaculture (Mexico, Panamá, Morocco, Japan, China), although the introductions only appear to have been successful in North and Central America (FAO 2022, Froese and Torres 2022), with variable success in Canada (Rawson and Ruttan 1952).

The popularity of Black Crappie as a panfish in the United States and some Canadian provinces, could cause pressure on Canadian fisheries managers to introduce the fish more widely to promote angling. For example, recreational fishing message boards in Saskatchewan (bite-me7 2015) and Alberta (spaghetti 2012) have threads calling for the stocking of Black Crappie and other panfish in those provinces.

2.4.2 Accidental live release

2.4.2.1 Live bait

A common mode of aquatic species invasion is introduction due to live bait escapes or the emptying of bait buckets (Litvak and Mandrak 1993). Black Crappie is not usually sought after as a bait fish, and if it is used, the preferred method is as cut bait (i.e. fish cut into pieces) (Enns 2022), which is a lower invasion risk than live bait. However, it is suspected that bait releases are partly to blame for some of the introductions in Maine in recent years (Lucas 2002).

2.4.2.2 Stocking error

In Manitoba, Black Crappie was introduced to the Whiteshell Provincial Park when they were accidentally included while stocking Smallmouth Bass (Hauger 2020). While the risk of further introductions of this kind is low compared to the other modes of invasion for this species, this kind of error could potentially occur elsewhere when stocking fish from an aquaculture facility that also rears Black Crappie.

2.4.2.3 Fishing translocations

Translocation of adult fish from one waterbody to another by fisherman is a potential risk in areas where Black Crappie are fished recreationally and are managed with bag limits. During a study of tagged Black Crappie in Whiteshell Provincial Park in Manitoba, Hauger (2020) was informed by anglers that they had released a tagged fish into a different waterbody from where it was landed. This occurred because the fisherman had caught the tagged fish, moved to a new waterbody and proceeded to catch another, larger Black Crappie. Having reached their bag limit for the day, they preferred to keep the larger fish instead of the smaller tagged one, so released the tagged fish into the new waterbody.

2.4.3 Illegal introductions

Next to authorized introductions, illegal introductions by the public for recreation are the second most common way for Black Crappie to spread, and have resulted in the species' expansion into multiple states and provinces. This kind of spread is often referred to as the 'bucket brigade'. Prior to 1985, Black Crappie distribution in Maine was restricted to 13 lakes, which expanded to 64 lakes across several drainages by 2002 due to illegal stocking and possibly live bait release (Boucher 2016, Lucas 2002). In Wyoming, it was concluded that 50% of

62 unauthorized fish introductions were due to intentional introduction by the public (Hauger 2020). In Canada, this method was the cause of Black Crappie spread into the Lower Fraser in British Columbia (Quinn and Paukert 2009) and is the likely mode of introduction in New Brunswick (Plourde 2021).

2.4.4 Escape from reservoirs and impoundments

Black Crappie stocked in reservoirs and aquaculture ponds have been known to escape due to flood or high-water events. In Colorado, Whitledge et al. (2007) found Black Crappie in the Colorado river to have originated from flood plain ponds and it is suspected that some of the Black Crappie populations currently found in México were the result of escapes and migration from dam reservoirs and irrigation systems in California and Arizona (Ruiz-Campos et al. 2014).

2.4.5 Natural dispersal

Although much of its spread throughout North America has been due to human interference, Black Crappie also have the capacity to spread large distances on their own. This is evidenced by the spread of Black Crappie through the Lower Fraser in British Columbia (McPhail and McPhail 2007, Carl and Guiguet 1958), into the Winnipeg River and Winnipeg Lake from Whiteshell Provincial Park in Manitoba (Langhorne et al. 2001), into Lake Superior from a neighbouring stocked lake (Scott and Crossman 1973), and into México from California and Arizona (Ruiz-Campos et al. 2014). In Florida, a mark-recapture study found 3 individuals had moved more than 99 km from their original capture location (Warren 2009).

In Maine, DeRoche and Foye (1954) documented the migration of Black Crappie from Virginia Lake to Sebago Lake (Fig. 6). Black Crappie were stocked in Virginia Lake in 1921, but remained contained until 1945 when a fish screen was removed from the outlet of the lake. By 1948 and 1949, specimens were found in Keewaydin Lake and Proctor Pond, approximately 2 km from Virginia Lake. By 1952, Black Crappie were being recorded in Sebago Lake, a distance of approximately 63 km from Virginia Lake.



Figure 6. Suspected migration path of Black Crappie from Virginia Lake after removal of fish screen from outlet, Maine, 1945 – 1952. Created with information from: DeRoche and Foye (1954).

3.0 BIOLOGY AND NATURAL HISTORY

3.1 LIFE CYCLE

Black Crappie are spring to late-spring spawners depending on their location. The males build nests and actively protect the eggs and very young larvae (Warren 2009, Edwards et al. 1982, Carlander 1977). The larvae begin to leave their nests in covered littoral habitat and head to the pelagic zone when they reach a minimum of 8–10 mm total length (TL), although most move at lengths of 50–60 mm TL (Wallus and Simon 2008, as cited in Culpepper&Allen 2016). Black Crappie larvae spend several weeks in the pelagic zone of the lake before returning to the littoral zone (Post et al. 1995). Juveniles begin their lives feeding primarily on zooplankton, and to a lesser extent, invertebrates, typically (but not always) becoming more piscivorous as they grow (see Section 3.4). Black Crappie reach sexual maturity between the ages of 1 and 4, although 2–4 is more typical (Warren 2009, Carlander 1977, Scott and Crossman 1973). Most reports from the United States show an average lifespan of 4 years (Carlander 1977, Ming 1971), with few populations having fish above the age of 6 (Jackson and Hurley 2005), although this can vary widely depending on location. Maximum age for Black Crappie in the United States has been recorded at 13 years (Carlander 1977), although multiple 14 and 15 year old individuals were recorded in studies in Manitoba (Hauger 2020).

3.2 AGE AND GROWTH

Black Crappie recruitment and growth is highly variable (Aday et al. 2009), not only varying regionally, but also between neighbouring waterbodies. The species is subject to periodic recruitment failures, overpopulation in small waterbodies (<100 ha) (Culpepper and Allen 2016, Ming 1971), and stunting (Ming 1971). Research has found that a wide array of biotic and abiotic factors can influence growth, recruitment, and survival of Black Crappie (Aday et al. 2009, Carlander 1977). The effects reported in the literature are sometimes conflicting between locations and can be population/waterbody specific (Table 2). The main variables that have been studied include: lake productivity, water retention (reservoirs and impoundments), fish community, food availability, hatching timing, lake depth/water level, latitude, population density, shoreline development, temperature, and turbidity. Differences in growth between males and females is negligible (Isermann et al. 2010).

The effect of lake productivity (as measured by chlorophyll-*a*) on Black Crappie growth is inconclusive. In Minnesota, a study of 42 lakes found a domed response curve for age-0 growth which peaked at chlorophyll-*a* concentrations of 100 µg/L and then declined thereafter (McInerny and Cross 1999). However, in Florida, age-0 fish weight was negatively correlated to increased chlorophyll-*a* (Matthias et al. 2018), while in Alabama, juvenile Black Crappie abundance increased with increasing chlorophyll-*a*, while age-0 abundance was unaffected (Dubuc and Devries 2002).

Table 2. Effect of abiotic and biotic variables on growth, recruitment, and survival of Black Crappie.

Location	Waterbody Size (ha)	Life Stage	Variable	Effect	Reference
Alabama	3 impoundments, 5060-15850 ha	Age-0	Adult characteristics	Larvae abundance not related to adult condition factor or fecundity	Dubuc and Devries 2002
Alabama	3 impoundments, 5060-15850 ha	Post-larval	Chlorophyll-a	Abundance of juvenile crappies increased with increased productivity	Dubuc and Devries 2002
Alabama	3 impoundments, 5060-15850 ha	Age-0	Chlorophyll-a	Larval abundance not related to chlorophyll-a concentrations	Dubuc and Devries 2002
Florida	2310 ha lake	Age-0	Chlorophyll-a	Weight negatively related to increased chlorophyll-a	Matthias et al. 2018
Florida	2310 ha lake	age-1+	Chlorophyll-a	Weight negatively related to increased chlorophyll-a	Matthias et al. 2018
Minnesota	42 Lakes	Age-0	Chlorophyll-a	Growth increased with increasing chlorophyll-a until ~100 µg/L, then decreased	McInerny and Cross 1999
Minnesota	42 Lakes	Age-0 to age-2	Climate warming	Growth unrelated to warming trends across lakes	McInerny and Cross 1999
Unspecified	Unspecified	Unspecified	Diet composition	Growth better where insects composed greater % of diet than where copepods did	Carlander 1977
Massachusetts	Lake	to Age-III	Fish community	Introduction of smelt perhaps reduced growth	Carlander 1977
Massachusetts	Lake	after Age-III	Fish community	Introduction of smelt increased growth	Carlander 1977
Minnesota	Lake	Unspecified	Fish community	No effect after carp removal	Carlander 1977
Pennsylvania	Lake	Unspecified	Fish community	Poorest growth when carp abundant	Carlander 1977
South Carolina	Cooling reservoir 7435 ha	Age-0	Fish community	Growth decreased when Threadfin Shad were present	Barwick and Lorenzen 1984
Unspecified	Unspecified	Unspecified	Fish community	Growth better after bass reduced Black Crappie population	Carlander 1977
Unspecified	Unspecified	Unspecified	Fish community	Years of good growth of Black Crappie were years of bad growth for White Crappie	Carlander 1977
Arizona	Unknown	Unspecified	Food availability	Threadfin Shad introduction increased avg. K	Carlander 1977
California	Various	Various	Food availability	Every stunted population had a paucity of forage fish	Carlander 1977
Ohio	5 reservoirs, 244–1145 ha	First feeding larvae (<10 days)	Food availability	Growth rates increased with total zooplankton biomass	Bunnell et al. 2003
Ohio	5 reservoirs, 244–1145 ha	Larvae (10-16 days)	Food availability	Survival increased with zooplankton biomass in 1 of 4 reservoirs	Bunnell et al. 2003
Alabama	3 impoundments, 5060–15850 ha	Age-0	Hatching timing	Growth slowest in lake with earliest hatch	Dubuc and Devries 2002
Florida	150 ha lake	Age-0	Hatching timing	Growth rates were positively correlated with later hatching	Pine III and Allen 2001
Florida	150 ha lake	Age-0	Hatching timing	Instantaneous mortality and survival to end of first summer was positively correlated with later hatching	Pine III and Allen 2001
Various	Various	Recruitment	Hatching timing	Among years, on average growth slower and higher mortality when hatch was earlier. Within years, growth was slower and mortality higher for individuals that hatched earlier.	Aday et al. 2009
Minnesota	42 Lakes	Age-0	Lake depth	Growth decreased with increasing mean depth	McInerny and Cross 1999

Table 2 (cont'd). Effect of abiotic and biotic variables on growth, recruitment, and survival of Black Crappie.

Location	Waterbody Size (ha)	Life Stage	Variable	Effect	Reference
Manitoba	Various	Age-1 to Age-15	Latitude	Growth was slower than southern populations but grew to larger sizes and ages	Hauger 2020
Wisconsin	Various	Unspecified	Latitude	More rapid in southern vs northern Wisconsin	Carlander 1977
South Dakota	Impoundment – 336 ha Natural lake – 405 ha	Age-0 to Age-4	Natural or impoundment / Population density	Growth slower in impoundment with higher abundance. Growth faster in natural lake with lower abundance.	Pope and Willis 1998
Florida	2310 ha lake	Various	Population density	Growth was 25% slower at higher density	Matthias et al. 2018
Florida	2310 ha lake	Age-1+	Population density	Weight negatively related to increased population density	Matthias et al. 2018
Iowa		Unspecified	Population density	Decreased density improved avg. K	Carlander 1977
Iowa	Lake	Unspecified	Population density	Reduction in population improved growth	Carlander 1977
Kansas	Lake	Unspecified	Population density	Growth better after removal of population and restocking	Carlander 1977
Minnesota	42 Lakes	Various	Population density	Growth to reach 200 mm faster with lower summer gillnet CPUE	McInerney and Cross 1999
Oklahoma	Lake	Unspecified	Population density	Reduction in population improved growth	Carlander 1977
Unspecified	Unspecified	Unspecified	Population density	Less dense populations reached 211 mm a year sooner than dense populations	Carlander 1977
Wisconsin	20.2 ha	Ages 1-4	Population density	Growth low and density high prior to removal of 90% of Black Crappie. Post removal, growth rates increased.	Hanson et al. 1983
Minnesota	80–525 ha lakes	Various	Sex	Growth of males was slightly faster, but differences were 15 mm or less for length, and less than 10g for weight	Isermann et al. 2010
South Dakota	Large impoundments (>40 ha), small impoundments (≤40 ha), natural lakes	Recruitment	Shoreline development index ¹	An increase in recruitment variability correlated with the log10 of the shoreline development index	Guy and Willis 1995
South Dakota	Lake	Unspecified	Surface Area, average depth, and water level fluctuation	32% of annual growth variation explained by variables	Carlander 1977
Florida	2310 ha lake	Various	Temperature	Growth had a positive, domed response with fastest growth at optimal temperatures (25.5°C), slower growth (48% less) at coldest (7°C) and slowest growth (82% less) at the hottest (32.2°C)	Matthias et al. 2018
Florida	2310 ha lake	Age-0	Temperature	Weight positively related to increased temperature	Matthias et al. 2018
Florida	2310 ha lake	Age-1+	Temperature	Weight negatively related to increased temperature	Matthias et al. 2018
Florida	150 ha lake	Age-0	Temperature	Growth increased with increased water temperature	Pine III and Allen 2001
Iowa (Clear Lake)	Lake	Unspecified	Temperature	No correlation with Apr-Oct temperatures	Carlander 1977
South Carolina	Cooling reservoir 7435 ha	Age-0	Temperature	Growth decreased at higher temperatures	Barwick and Lorenzen 1984

1, Shoreline development index “relates the measured shoreline length of a given lake to the shoreline length of a perfectly circular lake of equal area” (Aronow 1982) and is a measure of shoreline complexity.

Table 2 (cont'd). Effect of abiotic and biotic variables on growth, recruitment, and survival of Black Crappie.

Location	Waterbody Size (ha)	Life Stage	Variable	Effect	Reference
South Carolina	Cooling reservoir 7435 ha	Age-1 to Age-2	Temperature	Growth increased at higher temperatures	Barwick and Lorenzen 1984
South Carolina	Cooling reservoir 7435 ha	Age-1 to Age-3	Temperature	Growth increased when Threadfin Shad were present	Barwick and Lorenzen 1984
South Dakota	Impoundment – 336 ha Natural lake – 405 ha	Recruitment	Temperature	Year class strength did not appear to be affected by low spring temperatures.	Pope and Willis 1998
Unspecified	Reservoir	Unspecified	Thermal stratification	Growth usually more rapid thermally stratified reservoirs than unstratified or municipal water supply reservoirs	Carlander 1977
Oklahoma	45–200	Unspecified	Turbidity	Slower in turbid lakes of 45–200 ha compared to other	Carlander 1977
South Dakota	Lake	Unspecified	Turbidity	Population decline as turbidity increased	Carlander 1977
Unspecified	Ponds	Unspecified	Turbidity	Growth slower in turbid vs clear ponds	Carlander 1977
Ohio	5 reservoirs, 244–1145 ha	Larvae (10-16 days)	Various	Growth unrelated to temperature, turbidity, and density of all limnetic larvae	Bunnell et al. 2003
Florida	2310 ha lake	Age-1+	Water level	Weight negatively related to increased water level	Matthias et al. 2018
Indiana	Unspecified	Unspecified	Water level	Slower with lowered July water levels	Carlander 1977
Iowa (Clear Lake)	Lake	Unspecified	Water level	No correlation with water level	Carlander 1977
Michigan	Unspecified	Unspecified	Water level	Significant increase with 1 m increase	Carlander 1977
Various	Various	Recruitment	Water level	Strong year classes consistently associated with stable water levels during and after spawn	Aday et al. 2009
Various	Various	Unspecified	Water level drawdown to control populations	No effect on condition factor ²	Carlander 1977
Alabama	11 reservoirs, 2368–18300 ha	Age-0	Water retention	Recruitment positively related to short winter retention (Jan-Mar) prior to spawning and longer post winter retention (Apr-Dec)	Maceina 2003
Various	Impoundments	Recruitment	Water retention	Strong recruitment occurred in years with high discharge during pre-spawn period	Aday et al. 2009
South Dakota	Large impoundments (>40 ha), small impoundments (≤40 ha), natural lakes	Recruitment	Watershed to lake area ratio	An increase in recruitment variability correlated with the log10 of the watershed to lake area ratio	Guy and Willis 1995
Unspecified	Unspecified	Recruitment	Winter mortality	Recruitment not effected by winter mortality unless very severe	Aday et al. 2009
Minnesota	42 Lakes	Age-0 to Age-2	Yearly growth	71% of variation in number of years to reach 200 mm explained by Age-1 and Age-2 growth, none explained by age-0 growth	McInerney and Cross 1999

² , Condition Factor = $K = (W/L^3)100$

Black Crappie growth can be affected by competition with other fish species, but the relationship is often complicated. Because Black Crappie begin their lives as planktivores and invertivores and then shift to partial to complete piscivory later in life, they can compete for food resources with planktivores, invertivores, and piscivores, depending on their life stage. For example, the introduction of Threadfin Shad (*Dorosoma petenense*) (a forage fish) to a waterbody in Arizona increased the average condition factor of adult Black Crappie (Carlander 1977), however, in South Carolina, a study of age-0 fish found that growth decreased after Threadfin Shad were introduced, presumably due to food competition (Barwick and Lorenzen 1984). A similar situation arose in Massachusetts with the introduction of smelt, although in that study Black Crappie growth increased only for age-3 and older fish, while younger fish showed signs of decreased growth (Carlander 1977).

Length and weight growth response to temperature also shows age related differences. Age-0 Black Crappie weights in Florida were positively correlated to temperature and negatively correlated for age-1+ fish; while in South Carolina growth in length for age-0 fish was negatively correlated to temperature (Matthias et al. 2018), and positively correlated for age-1+ fish (Barwick and Lorenzen 1984). In South Dakota, low water temperatures during spring did not appear to impact year class strength (Pope and Willis 1998). Rates of winter mortality appear to have a negligible effect on recruitment, unless very severe (Aday et al. 2009).

Black Crappie growth rate trends are often inversely related to those of White Crappie when they co-occur. However, this is thought to be more related to opposite responses to environmental conditions (such as turbidity) than due to direct competition between the two species (Carlander 1977).

In terms of the effect on the recruitment and survival of Black Crappie cohorts, hatching timing, stable water levels, turbidity (Aday et al. 2009), shoreline development, and watershed to lake ratio (Guy and Willis 1995) can all appear to play a role. Years with earlier hatches on average had better growth rates than those with later hatches (Pine III and Allen 2001). However, within a given year, the earliest hatched individuals had higher mortality and slower growth rates than those that hatched later (Dubuc and Devries 2002, Pine III and Allen 2001). Stable water levels during and after spawning consistently was associated with strong cohorts (Aday et al. 2009). In impoundments, short winter retention and discharge prior to the spawning period and longer retention post-spawning was associated with strong recruitment (Maceina 2003).

In a South Dakota study of 22 populations from large impoundments (>40 ha), small impoundments (≤40 ha), and natural lakes, Guy and Willis (1995) found that: small impoundments had Black Crappie populations with high densities, more stable recruitment, slow growth, and low condition factors; while natural lakes had populations with low density, unstable recruitment, fast growth rates, and high condition factors; and large impoundments overall were intermediate between the other two. The results from this study were partially due to a correlation between increased recruitment variability and increased shoreline complexity, which tended to be higher in natural lakes.

Black Crappie recruitment and growth is negatively associated with increased turbidity (Mitzner 1991), but the mechanism behind this is still unclear (Aday et al. 2009, Carlander 1977). Some theories include negative effects on zooplankton abundance, or negative impacts on foraging success (Aday et al. 2009). However, overall zooplankton abundance is not strongly correlated with Black Crappie growth and survival with some populations showing a positive effect, while others found no effect on growth beyond the first-feeding larval stage (Bunnell et al. 2003).

Overall, Black Crappie populations have been found to have either sigmoidal or non-sigmoidal growth curves, which has been linked to their overall growth rate. In a study of 42 Minnesotan lakes, sigmoidal growth curves were found in 70% of the fast-growing populations, while all of the slow growing populations had non-sigmoidal curves (McInerny and Cross 1999). As well, sigmoidal growth curves were associated with lakes with lower population densities (as determined by gillnet catch), while non-sigmoidal curves were associated with higher densities.

3.2.1 Standard growth and weight equations

3.2.1.1 United States

Jackson and Hurley (2005) developed a standard growth equation for Black Crappie based on data collected from 81 populations across the United States (Equation 1). The data used to develop the equation did not include fish over the age of 6 as few of the population datasets used had fish above that age and they typically saw a decline in growth after that point. The model was also based on scale ages, which are less accurate for assessing Black Crappie age than otoliths, particularly for southern populations (Jackson and Hurley 2005, Ross et al. 2005)

$$L_s = 286 (1 - e^{-0.443(age-0.273)}) \quad (1)$$

Where:

L_s = predicted age-specific standard length (mm)

age = age of the fish

Neumann and Murphy (1991) developed a standard weight-length equation for Black Crappie based on data from 80 populations across the United States (Equation 2).

$$\log_{10} W_s = -5.618 + 3.345 \log_{10} TL \quad (2)$$

Where:

W_s = weight (g)

TL = total length (mm)

3.2.1.2 Manitoba

Hauger (2020) developed a growth curve for seven Black Crappie populations across the Whiteshell Provincial Park in Manitoba (Equation 3). The growth curve included data for fish between age 1 and 15 and was based on otolith age assessments.

$$TL_A = 382(1 - e^{-0.248(age-0.152)}) \quad (3)$$

Where:

TL_A = total length (mm) at age

age = age of the fish

When compared to the growth curve of Jackson and Hurley (2005), the Manitoba growth curve suggests that the Whiteshell population grows slower on average than the Black Crappie populations in the United States. However, the calculated maximum growth length of Black Crappie in the United States was 286 mm versus 383 mm in the Manitoba population (Hauger 2020), meaning they grow slower, but longer than the southern populations. This discrepancy may also be a function of the truncated age used in calculating the United States curve which removed the few older and larger individuals.

A standard weight-length equation was also developed for the Whiteshell Black Crappie population (Hauger 2020) (Equation 4). When the standard length-weight equation was used to calculate the relative weight (a measure of body condition) of the Manitoba Black Crappie, their condition was found to be higher or similar to those found in populations further south.

$$\log_{10}W_s = -5.280 + 3.204 \log TL \quad (4)$$

Where:

W_s = weight (g)

TL = total length (mm)

3.3 REPRODUCTION

3.3.1 Spawning

Sexual maturity for Black Crappie is typically reached between the ages of 2–4 (Warren 2009) at about 175–200 mm TL (Edwards et al. 1982), although for fast growing individuals, maturity can be reached as low as 1 year of age (Carlander 1977). Most of the brood fish used in aquaculture mature at the age of 2, with some at 3 and some at 1 (Morris and Clayton 2009). In overcrowded populations, Black Crappie may spawn at smaller sizes (Riso 2011).

Spawning occurs in the spring, typically between temperatures of 14–22°C but can occur up to 26°C, with peak activity at most nests occurring around 18°C (Warren 2009). However, there are variations to this, for example, spawning initiated around 12°C in Mississippi reservoirs (Parsons 2015) and peak spawning occurred in Iowa around 21°C (Mitzner 1991). The spawning period is most protracted in the southern populations, in Florida occurring over a 12 week period from late January to May, with peaks in March and April (Warren 2009). In the north, spawning typically starts between April and June, but may run into July and lasts between 21–

37 days (Warren 2009). A South Dakota study found that the population as a whole spread out its spawning times and that spawning peaks within the spawning period were not necessarily indicative of multiple spawning by the same individuals (Pope and Willis 1998). In Manitoba, spawning likely occurs in late May (Hauger 2020), while in Ontario spawning occurs between mid-May to June between temperatures of 12–23°C (Carlander 1977). In some places, there is evidence that increasing water levels can also be triggers for the initiation of spawning (Aday et al. 2009).

Females can have 1 to 3 stages of maturing eggs within their ovaries, indicating the potential for multiple spawns in one season (Warren 2009, Pope et al. 1996a). In southern populations, some populations may have a second spawn in October or early November, although this is not common (Nagid et al. 2004, Carlander 1977).

Prior to spawning, males move from deeper over-wintering habitat to the littoral zone to establish territories and build nests (Warren 2009). Males have been known to move 0.4 to 6 km to find suitable spawning habitat (Warren 2009), with one paper reporting high fidelity to particular spawning coves (Gaston 2011). Smaller males typically move to spawning areas first and females are attracted to the area prior to nest building (Carlander 1977).

Black Crappies are more fecund than other centrarchids, with the exception of White Crappie (Warren 2009), with females typically producing between 20,000 and 188,000 eggs per female (Auer 1982). However this can be much larger, as a study in Illinois estimated eggs per female ranged from 33,940 to 348,400 for fish 225–322 mm, with a mean relative fecundity of 411 ova per gram, or 5000 ova per cm of total length. Eggs are amber coloured, demersal, adhesive, and have a single oil globule (Auer 1982, Carlander 1977). Mature ovarian eggs have a diameter ranging from 0.68–1.05 mm, while water-hardened eggs range from 0.76–1.03 mm, and water-hardened fertilized eggs average 1.27 mm (Warren 2009). Pope et al. (1996a) found when two modes of eggs were present in a female, the more developed eggs were more numerous, indicating the females put more energy into their first spawn than the second.

Fecundity increases with female length and weight (Warren 2009, Baker and Heidinger 1994). The relationship between the number of mature eggs and total length is described by Equation 5 (Warren 2009).

$$Y = 0.0279X^{2.6148} \quad (5)$$

Where:

Y = number of mature eggs

X = total length (mm)

Egg incubation occurs over a couple of days with hatching occurring in 2.0 days at 17.4°C (Cooke and Philipp 2009) and 2.4 days at 18.3°C (Warren 2009).

Once spawning has occurred, males guard the eggs and newly hatched larvae will actively drive invaders like carp (Carlander 1977) and sunfish (Warren 2009) from the area. In the northern part of the range, male Black Crappie parental care takes place over 7–11 days from egg deposition until the larvae disperse (Warren 2009). Newly hatched larvae are around 2.3 mm and swim-up larvae about 4 to 5 mm (Warren 2009). When the larvae reach the swim-up stage, they disperse (Warren 2009) into the pelagic zone of the lake, where they reside for between 2 to 6 weeks, after which they return to the littoral zone (Post et al. 1995).

After spawning, the gonad development of both males and females declines throughout the summer and then begins to increase again in the fall in preparation for the spring spawn (Hauger 2020, Gaston 2011).

3.3.2 Nests

Black Crappie nests are typically more widely spaced than other centrarchids, but can range from 3.3 nests/m² (Carlander 1977) to 1.8 m apart (Warren 2009). One instance of colonial nesting with more than 10 individual nests in close proximity was recorded in Illinois (Phelps et al. 2009). Nests are typically built at the base of, or near aquatic vegetation (Hubbs et al. 2004, Carlander 1977), are more likely to be built on firmer substrates, like clay or sand (Phelps et al. 2009), and are typically associated with some form of cover which may include woody debris (Pope and Willis 1997). A more detailed description of nesting habitat is provided in Section 3.5.2.

A study in South Dakota compared nest selection in an impoundment and a natural lake (Pope and Willis 1997). Males in both lakes selected areas that were protected from wind and wave action and associated with some kind of cover (a dense cattail stand in the lake and woody debris in the impoundment). In an Illinois lake, nests in 10 nest colonies were compared to non-nest areas and it was found that nests were always located near deep water (3.8 m); in low-density, short vegetation (compared to none, moderate or tall); and on firm clay or sand substrates (Phelps et al. 2009). Sixty percent of substrates at unused sites consisted of muck. Temperature and dissolved oxygen was significantly higher at nest sites versus non-nest sites. They also found two of the largest colonies at the lake's marina. In Iowa, nest sites were associated primarily with moderately firm substrates (Mitzner 1991). In Minnesota, studies across 3 lakes found Black Crappie were more likely to nest adjacent to undeveloped shoreline and in stands of emergent vegetation, particularly Hardstem Bulrush (*Schoenoplectus acutus*) (Reed and Pereira 2009).

3.4 FEEDING AND DIET

3.4.1 Diets

Black Crappie can be classified as primarily midwater invertivores (Warren 2009), although they start their lives as planktivores focused primarily on planktonic Crustacea and other small invertebrates, shifting to an ever increasing piscivorous diet as they increase in size (Keast 1968a). Black Crappie are well adapted to plankton feeding compared to other centrarchids as

their first gill arch has 25–29 gill rakers compared to 8–12 on non-*Pomoxis* species (Carlander 1977). Across their range, Black Crappie have shown a high degree of flexibility in their diets, readily switching food sources when prey items become scarce or abundant (Ming 1971). During an aquaculture study, ponds were treated with a chemical which killed off Dipterans, a major prey item for the population, and Black Crappie readily switched to the other prey items available with no detrimental impacts to their overall condition over time (Colwell and Schaefer 1980).

There have been numerous studies conducted on the diet of young Black Crappie. While there are variations across studies in terms of overall composition of the prey items consumed, the dominant prey groups are broadly similar across its range (Carlander 1977, Keast 1968a), with the diets in the northern part of the range most similar (Keast 1968a). Copepods consistently make up the bulk of juvenile Black Crappie diets across its range (Pelham et al. 2001, Pine III and Allen 2001, Pope and Willis 1998, Schael et al. 1991, Hanson and Qadri 1984, Carlander 1977). Other important prey groups for juveniles include: Chironomids (Hanson and Qadri 1984), Cladocerans (Pine III and Allen 2001, Ellison 1984, Carlander 1977), Chaoborus (Hanson and Qadri 1984, Carlander 1977), Ostracods (Carlander 1977), and Arthropods in general (Hanson and Qadri 1984). In many areas, *Daphnia* can make up a large part of Black Crappie diet (Howell et al. 2014, Pine III and Allen 2001, Pope and Willis 1998), although in other areas, Black Crappie have been shown to avoid consuming *Daphnia* (Andree and Wahl 2019).

In a study in Ontario by Keast (1968a), there was a progressive change in Black Crappie diets as the fish grew. For Black Crappie 60–115 mm long, their diets were dominated by planktonic Crustacea and small-bodied Diptera larvae, which shifted to one dominated by a diet of insect larvae and fish for Black Crappie 160–240 mm. Most of the prey items consumed were midwater forms, with the Diptera larvae almost entirely composed of *Chaoborus* and *Procladius*, which are free-swimming in the water column at night. The fish in this population had a prolonged Cladocera-Copepoda eating phase that continued to age-3 and 160 mm body length.

Diet composition in Black Crappie shows seasonal variation and the dominant prey groups consumed can change depending on the prey available in the environment. In Ontario, while Cladocera, Diptera, and Copepoda were the dominate prey items for juveniles overall, other groups like Ephemeroptera, Anisoptera, Amphipoda, Zygoptera, and fish could be the dominant prey group for individual months (Keast 1968a). In Ontario in the spring, diets were almost entirely composed of Chironomids, which only made up a small proportion of their diet in the summer (Keast 1968b). For age-1 Black Crappie in Iowa, spring diets were composed of both fish and invertebrates, with fish becoming more prevalent as the spring and summer progressed and more fry became available (Pelham et al. 2001).

Black Crappie typically start to switch to a fish-based diet only when they become large enough that feeding primarily on small prey becomes physiologically impractical (Keast 1968a). The introduction of fish into the Black Crappie diet can occur as early as age-1 (Liao et al. 2002, Pelham et al. 2001), but can begin later, and in some populations and individuals, never occurs

(Ellison 1984). As adults, the prevalence of fish in Black Crappie diets can be variable within and across populations ranging from none to full piscivory, particularly in larger individuals. In Iowa, the diets of Black Crappie >150mm were composed primarily of Amphipoda (49.8%) with lesser components of Diptera, Ephemeroptera, and Odonata, along with Yellow Perch (*Perca flavescens*) (5.7%) and Bluegill (*Lepomis macrochirus*) (2.9%) (Liao et al. 2002). Liao et al. (2002) also found that the differences in the onset and extent of piscivory in juveniles persist as adults. Ellison (1984) found that adult Black Crappie that never transitioned to eating fish do not live as long as conspecific White Crappie that did eat fish, as well as growing slower and having higher mortality rates during heat events in the summer. Other Canadian fish species known to be consumed besides Yellow Perch and Bluegill include: Pumpkinseed (*Lepomis gibbosus*), Blackchin Shiner (*Miniellus heterodon*), Golden Shiner (*Notemigonus crysoleucas*), Bluntnose Minnow (*Pimephales notatus*), Freshwater Drum (*Aplodinotus grunniens*), Logperch (*Percina caprodes*), Largemouth Bass, and Smallmouth Bass (Pelham et al. 2001, Keast 1968b). In hatchery and aquaculture settings, cannibalism can be an issue when rearing Black Crappie (Culpepper and Allen 2016) and cannibalism has also been recorded in the wild (Keast 1968a).

Juvenile Black Crappie diets are generally not gape limited. When they initially start to feed, young Black Crappie will select for prey items as big as their gape, however, as they continue to grow, the ratio between prey size and fish size gets larger as they continue to select for the smallest prey (Schael et al. 1991, Ellison 1984, Hanson and Qadri 1984). Hanson and Qadri (1984) noted that age-0 Black Crappie prey selection did not conform to what is expected of a visual feeding planktivore (i.e. suction feeding) as they often ate calanoid copepods and Chaoborus larvae, which are known to evade suction feeding. As such, they suggest that Black Crappie employ a different type of plankton feeding that does not generate suction currents.

3.4.2 Feeding behavior

Newly hatched Black Crappie larvae survive on their yolk-sac which is usually depleted by the time they reach sizes of 3–6 mm in length (Auer 1982). After this stage, they start consuming plankton and migrate to the pelagic zone for several weeks, before returning to the littoral zone (Post et al. 1995).

Juvenile Black Crappie are diurnal feeders, feeding in several pulses during the day, and stopping around sunset (Ellison 1984, Hanson and Qadri 1984). In a study in Ontario by Hanson and Qadri (1984), age-0 Black Crappie commenced feeding near sunrise, had a peak in stomach fullness near 10:00 AM, almost stopped feeding by early afternoon, and had another smaller feeding period near sunset.

Adult Black Crappie are primarily nocturnal feeders, although smaller individuals (<15 cm) occasionally feed in the afternoon (Helfman 1981). In Manitoba, adult Black Crappie were found to have different feeding strategies between lakes, with some feeding more in the littoral zone while others focused on the pelagic zone (Hauger 2020). The reason for this difference remains unclear.

In the northern part of its range, Black Crappie feed very little over winter, stopping feeding in late fall or early winter (Keast 1968a) and resuming feeding in the spring when water temperatures reach about 6.5°C (Carlander 1977). However, Black Crappie will feed occasionally during winter as is evidenced by their popularity with ice fishermen in some areas (Suski and Ridgway 2009, Keast 1968b). Southern populations feed year-round (Keast 1968a).

In Ontario in the spring, Black Crappie began to feed before temperatures reached 7°C, and started feeding before Pumpkinseed, Yellow Perch, and Rock Bass, but after Black Bullhead (*Ameiurus nebulosus*) (Keast 1968b).

3.5 HABITAT REQUIREMENTS

3.5.1 General Habitat

Black Crappie are associated with clear, still, vegetated waters in lakes and rivers (Page and Burr 2011, Aday et al. 2009, Hubbs et al. 2004). Although more commonly found in the still waters of lakes, reservoirs, and impoundments they can also be common in the shallows, pools and backwaters of large rivers, however, they may not be present in the adjoining tributaries (Edwards et al. 1984). They are absent from high gradient streams, but are common in base and low gradient streams (Edwards et al. 1984). In a comparative study of 60 natural lakes in Florida, probability of Black Crappie presence increased with increasing lake surface area and productivity (chlorophyll- α concentration) (Allen et al. 1998). Within lake habitats, they tend to do poorly in the main body of large lakes, but can be abundant in shallow areas and bays (Edwards et al. 1984).

Almost always associated with aquatic vegetation (Miller et al. 2018, Page and Burr 2011, Hubbs et al. 2004), Black Crappie have been known to persist in unvegetated habitat, although they do not do well (Edwards et al. 1984). Black Crappie have body morphologies that improve maneuverability and predator avoidance in vegetated habitats compared to open water habitats (Porreca et al. 2020) and they build their nests at the base of aquatic vegetation (Hubbs et al. 2004, Carlander 1977). Heavily associated with clear waters, it is uncertain why Black Crappie do poorly in turbid environments, although it is likely associated with turbidity's negative effect on aquatic vegetation (see Section 3.8.1). Once juvenile Black Crappie leave the nest, they spend several weeks in the pelagic zone, before returning to the vegetated areas of the littoral zone (Weber and Brown 2012, Post et al. 1995).

Usually found in freshwater, Black Crappie can occasionally be found in brackish water (Edwards et al. 1984). While their preferred temperature range has been recorded as 27–29°C (Kieffer and Cooke 2009, Edwards et al. 1984), with the optimal growth range for juveniles around 22–25°C (Edwards et al. 1984), Black Crappie can survive in waters up to the mid-thirties (Baker and Heidinger 1996) and down to temperatures as low as 1°C for short periods of time (Knights et al. 1995). Dissolved oxygen concentrations above 2.6 mg/L are sufficient for successful reproduction (Carlson and Herman 1978).

More detailed information on Black Crappie tolerance to various habitat conditions can be found in Section 3.8.

3.5.2 Spawning Habitat

Black Crappie nests are typically built at the base of aquatic vegetation (Hubbs et al. 2004, Carlander 1977) on firmer substrates (Phelps et al. 2009) at depths less than 3 m (Hanson et al. 1983).

A study in South Dakota compared nest selection in an impoundment and a natural lake (Pope and Willis 1997). Males in both lakes selected areas that were protected from wind and wave action and associated with some kind of cover (a dense cattail stand in the lake and woody debris in the impoundment).

In an Illinois lake, nests in 10 nest colonies were compared to non-nest areas and it was found that nests were always located near deep water (3.8 m); in low-density, short vegetation (compared to none, moderate or tall); and on firm clay or sand substrates (Phelps et al. 2009). Sixty percent of substrates at unused sites consisted of muck. Temperature and dissolved oxygen was significantly higher at nest sites versus non-nest sites. They also found two of the largest colonies at the lake's marina.

In Iowa, nest sites were associated primarily with moderately firm substrates (Mitzner 1991). In Minnesota, studies across 3 lakes found Black Crappie were more likely to nest adjacent to undeveloped shoreline and in stands of emergent vegetation, particularly Hardstem Bulrush (Reed and Pereira 2009).

3.5.3 Habitat Suitability Index (HSI)

Edwards et al. (1984) developed a habitat suitability index (HSI) model for Black Crappie in lacustrine and riverine systems to aid in impact assessment and habitat management activities. The model was developed based on the potential for Black Crappie to be present in a location given its preferred habitat and environmental tolerances and is not necessarily an indicator of potential Black Crappie population size. The model produces an index value between 0 (unsuitable habitat) and 1 (optimal habitat). A summary of the HSI model is provided below including all equations used in the model (Table 4), descriptions of the variables and inputs required to run the model (Table 3), and graphs of the suitability indexes for each of the variables (Figs 7 & 8). Detailed explanations on the details of the model can be found in Edwards et al. (1982).

3.5.4 Habitat suitability in New Brunswick

The conditions in slower moving, vegetated sections of the Saint John River would provide suitable habitat for Black Crappie. While Black Crappie are primarily a lake species, they can be found in the slow-moving portions (pools, backwaters, and bays) of large rivers (Edwards et al. 1984), including hydroelectric reservoirs which may create prime habitat. While the fast moving portions of the Saint John River show velocities greater than those tolerated by Black Crappie, the edges of the river have velocities in its preferred range (Table 5).

Water quality data collected quarterly between 2003-2015 in the Saint John River upstream and downstream of the Mactaquac Generating Station (MGS) (Stantec 2016) is summarized in Table 6 alongside known Black Crappie tolerances. Dissolved oxygen, pH, alkalinity, potassium, and sodium in the Saint John River were all within the acceptable tolerances of Black Crappie. While average turbidity levels were also within Black Crappie tolerances, maximum values exceeded tolerance levels. Average temperatures within the river are lower than Black Crappie preferred temperatures, but are still well within the tolerance range for survival of all life stages and for spawning activity. Average river temperatures are lower than the optimum range for juvenile growth, but are still 4°C above the minimum growth temperature.

Table 3. Description of variables used in Black Crappie Habitat Suitability Index model (Edwards et al. 1982).

Habitat	Variable	Measured Value	Description
River (R) or lake (L)	V ₁	Turbidity (JTU)*	Maximum monthly average turbidity (JTU) during summer.
River or lake	V ₂	Cover (%)	Percent cover (e.g. vegetation, brush, debris, and standing timber) during mid-summer within pools, overflow areas, and backwaters (R), and the littoral zone (L).
River	V ₃	Stream gradient (m/km)	Stream gradient within study area (m/km).
River	V ₄	Current velocity (cm/s)	Average current velocity (cm/s) in pools and backwater areas during average summer flow.
River	V ₅	Pools and Backwater Areas (%)	Percent pools and backwater areas during average spring and summer flow.
Lake	V ₆	Littoral Area (%)	Percent littoral area during spring and summer.
River or lake	V ₇	pH	pH levels during year.
River or lake	V ₈	Temperature (°C)	Most suitable water temperature within the epilimnion (L) or in pools and backwaters (R) during midsummer (adult). NOTE: Choose the epilimnion with the highest suitability index [#] rating for water temperature (see Fig. 7).
River or lake	V ₉	Temperature (°C)	Most suitable water temperature within the epilimnion (L) or in pools and backwaters (R) during midsummer (juvenile). NOTE: Choose the epilimnion with highest suitability index rating for water temperature (see Fig. 7).
River or lake	V ₁₀	Temperature (°C)	Average water temperature within littoral areas (L) or in pools and backwaters (R) during mid-summer (fry).
River or lake	V ₁₁	Temperature (°C)	Average water temperature within littoral areas (L) or backwaters (R) during spawning (embryo).

Habitat	Variable	Measured Value	Description
River or lake	V ₁₂	Dissolved oxygen (mg/L)	Minimum dissolved oxygen levels within temperature strata selected above (V ₈ , V ₉ , and V ₁₀) during midsummer (adult, juvenile, fry).
River or lake	V ₁₃	Dissolved oxygen (mg/L)	Minimum dissolved oxygen levels within littoral areas (L) or backwaters (R) during spawning (embryo, fry).
Lake	V ₁₄	Salinity (ppt)	Maximum salinity during growing season. NOTE: V ₁₄ may be omitted if salinity is not considered to be a potential problem within the study area.
Lake	V ₁₅	Total Dissolved Solids (TDS) (ppm)	Average TDS level during the growing season. NOTE: Suitability index value (see Fig. 8) should be lowered 0.2 if ionic concentration of sulfate-chlorides exceeds that of carbonate-bicarbonates.

R = River, L = Lake, JTU = Jackson Turbidity Units,

*Jackson Turbidity Units. Historic turbidity measurement based on visual assessment with the Jackson candle turbidimeter. The development of Nephelometric Turbidity Units (NTU) was based on JTUs and while not directly equivalent, JTUs and NTUs can be interconverted within statistical limits (Telesnicki and Goldberg 1995).

#, Suitability index graphs showing the range of values for each variable that are suitable (1.0) or unsuitable (0.0) for the successful reproduction of Black Crappie are provided in Edwards et al. (1982).

Table 4. Habitat Suitability Index (HSI) model equations for riverine and lacustrine habitats.

Model	Component	Equation	Notes
Riverine	HSI Determination	$HSI = (C_C C_{WQ} C_R C_{OT})^{1/4}$	Or, if C_{WQ} or C_R is ≤ 0.4 , then HSI equals the lowest of the following: C_{WQ} , C_R , or the above equation.
	Food-Cover (C_{F-C})	$C_{F-C} = (V_2 V_5)^{1/2}$	
	Water Quality (C_{WQ})	$C_{WQ} = \frac{2((V_8 V_9 V_{10})^{1/3}) + 2V_{12} + V_7 + V_1}{6}$	If $(V_8 V_9 V_{10})^{1/3}$ or V_{12} is ≤ 0.4 , C_{WQ} equals the lowest of the following: $(V_8 V_9 V_{10})^{1/3}$ or V_{12} or the above equation. If either V_8 , V_9 , or V_{10} is ≤ 0.4 , then $(V_8 V_9 V_{10})^{1/3}$ equals the lowest rating. V_{14} , optimal salinity, is an optional variable only required if salinity is a potential issue.
	OR, if V_{14} is added:	$C_{WQ} = \frac{2((V_8 V_9 V_{10})^{1/3}) + 2V_{12} + V_7 + V_1 + V_{14}}{7}$	
	Reproduction (C_R)	$C_R = (V_2 V_5 V_{11}^2 V_{13}^2)^{1/6}$	
	Other (C_{OT})	$C_{OT} = \frac{V_3 + V_4}{2}$	
Lacustrine	HSI Determination	$HSI = (C_F C_C C_{WQ} C_R)^{1/4}$	Or, if C_F , C_C , C_{WQ} or C_R is ≤ 0.4 , then HSI equals the lowest of the following: C_F , C_C , C_{WQ} or C_R or the above equation.
	Food (C_F)	$C_F = V_{15}$	
	Cover (C_C)	$C_C = (V_2 V_6)^{1/2}$	
	Water Quality (C_{WQ})	Same as riverine model	
	Reproduction (C_R)	$C_R = (V_2 V_6 V_{11}^2 V_{13}^2)^{1/6}$	

Source: Edwards et al. 1982.

3.6 SPECIES INTERACTIONS

In several instances in the literature, non-forage fish and Black Crappie abundances can be correlated. However, many of these instances were linked to environmental conditions rather than direct interactions between the species. Black Crappie and White Crappie often co-occur, not because of a special interaction between the two species but because they are often introduced and/or stocked together. The two species can often display opposite population trends (one increasing, one decreasing), but most researchers agree that this is due to different

responses to external factors like turbidity, with Black Crappie being intolerant to turbidity while White Crappie is more tolerant (Aday et al. 2009).

Further examples of coupled environmental responses were found between Black Crappie and White Bass (*Morone chrysops*), Bluegill, and Yellow Perch. In Nebraska, Black Crappie abundance was positively correlated to year-class strength of White Bass, which was attributed to resource conditions favouring recruitment in both species (DeBoer et al. 2013). Studying data from 130 lakes in Indiana over 30 years, Feiner et al. (2019b) found that Black Crappie and Bluegill recruitment was significantly positively correlated when the species coexisted. However, they ultimately concluded this was due to a similar response to wind as the relative year-class strength of both species was positively related to mean annual wind speed.

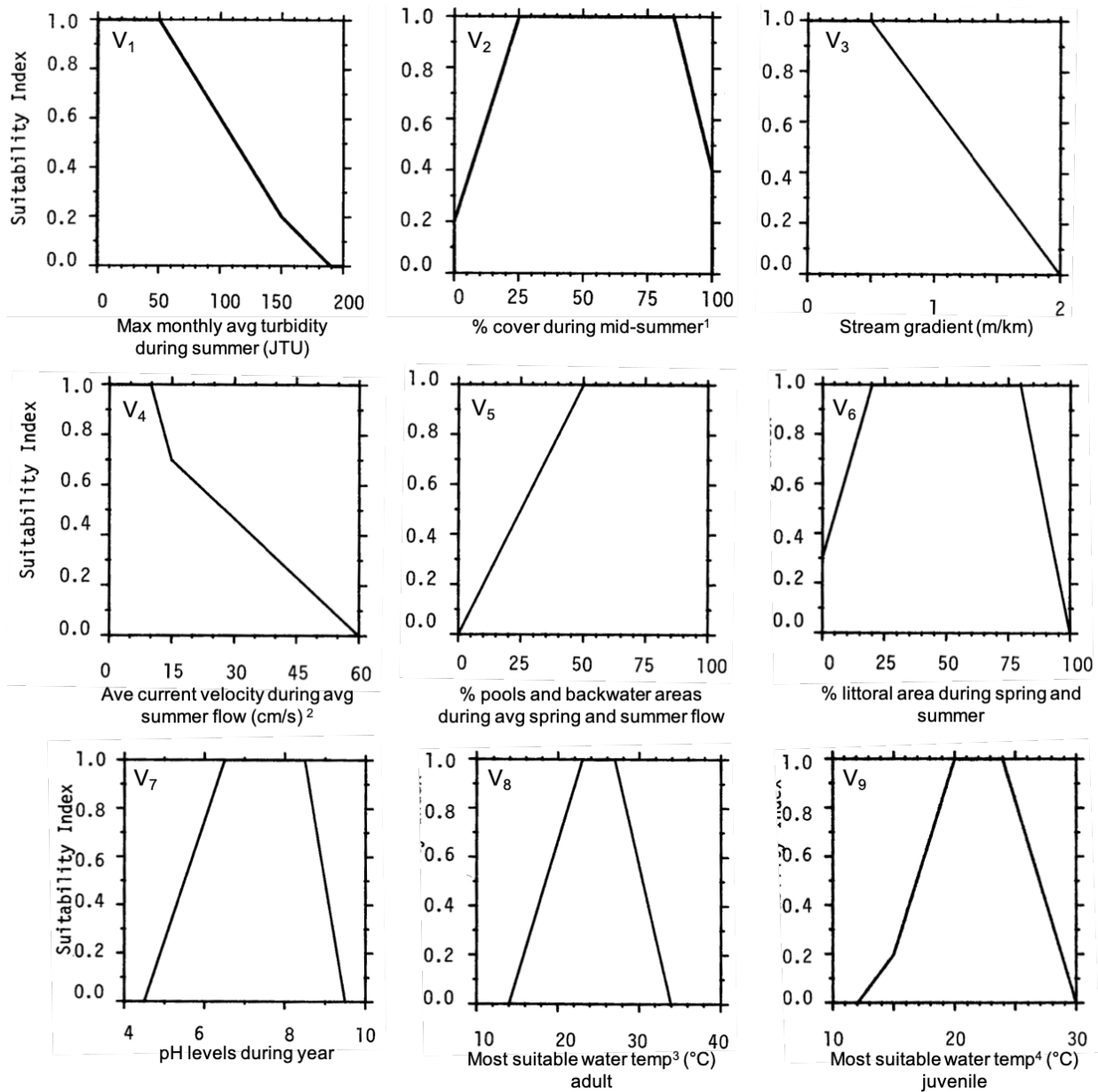


Figure 7. Suitability index graphs for variables 1-9 for Black Crappie Habitat Suitability Index (Edwards et al. 1984). R = Rivers, L = Lakes. 1, % cover during mid-summer within pools, overflow areas, and backwaters (R) and the littoral zone (L). 2, Average current velocity in pools and backwater areas during average summer flow. 3, Most suitable water temperature within the epilimnion (L) or in pools and backwaters (R) during midsummer (adult). 4, Most suitable water temperature within the epilimnion (L) or in pools and backwaters (R) during midsummer (juvenile).

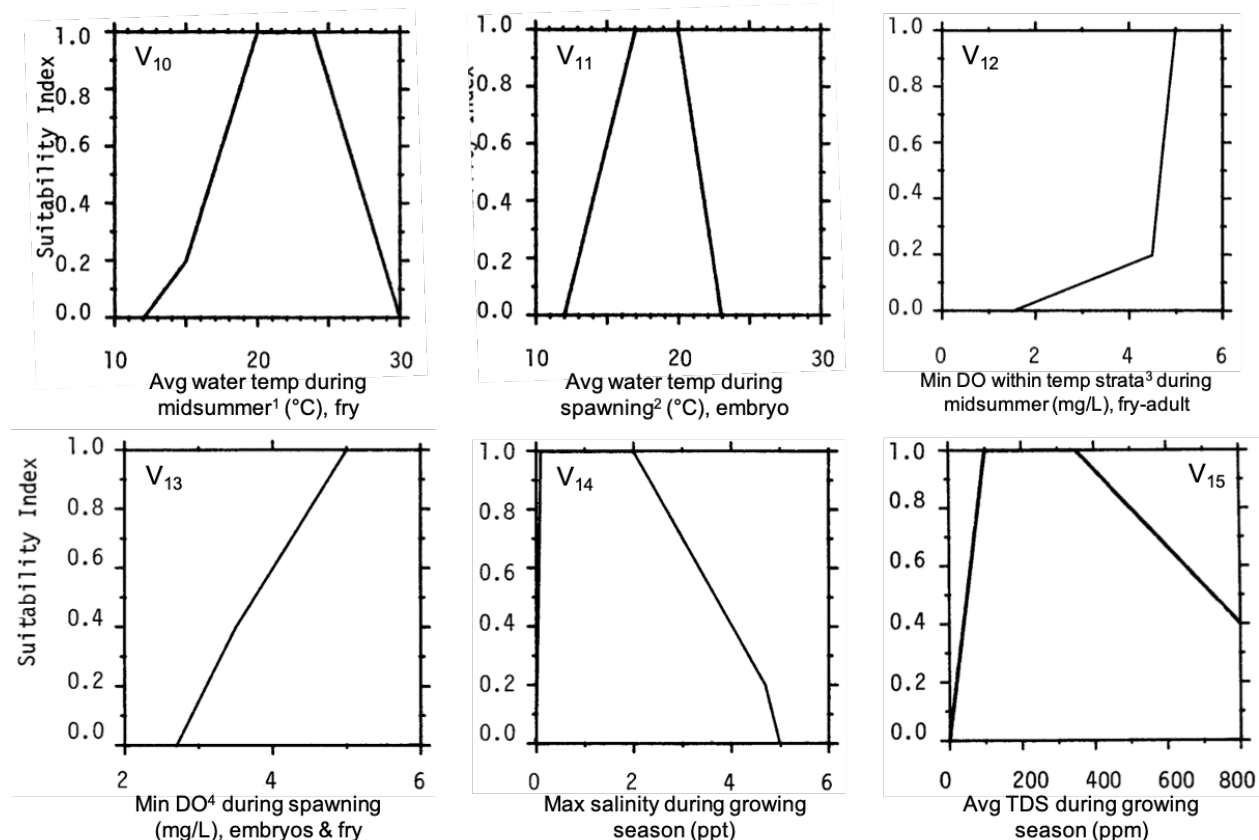


Figure 8. Suitability index graphs for variables 10-15 for Black Crappie Habitat Suitability Index (Edwards et al. 1984). R = Rivers, L = Lakes. 1, Average water temperature within littoral areas (L) or in pools and backwaters (R) during midsummer (fry). 2, Average water temperature within littoral areas (L) or backwaters (R) during spawning (embryo). 3, Minimum DO within temperature strata selected above (V8, V9, V10) during midsummer (fry-adult). 4, Minimum DO within littoral areas (L) or backwaters (R) during spawning (embryo, fry)

Table 5. Summary of water velocities collected during benthic macroinvertebrate sampling between 2014–2017 in Saint John River in the vicinity of Mactaquac Generating Station (MGS) compared to Black Crappie tolerances.

Habitat	Average Velocity (cm/s)			Maximum Velocity (cm/s)			Black Crappie Tolerances (cm/s)	References
	Mean	Min	Max	Mean	Min	Max		
Edge	3.4	-4.0	28.0	7.4	-4.0	71.0	Preferred: <10 Not present: >60 Winter max: <1	Edwards et al. 1984, Knights et al. 1995
Edge – Pool	15.8	-1.0	31.0	27.5	-1.0	69.0		
Edge – Riffle	3.0	-1.0	11.0	6.0	0.0	22.0		
Riffle	60.5	2.0	816.0	71.5	4.0	858.0		

Velocity data source: Dolson-Edge et al. 2019

Table 6. Summary of water quality parameters collected quarterly 2003–2015 in Saint John River in the vicinity of Mactaquac Generating Station (MGS) compared to Black Crappie tolerances.

Parameter	Units	Upstream of MGS			Downstream of MGS			Black Crappie Tolerances	References
		Mean	Min	Max	Mean	Min	Max		
Turbidity	NTU	5.5	0.3	441	3.4	0.4	52.8	Max average monthly summer turbidity: 0-50 JTU*	Edwards et al. 1984
Temperature	°C	15.7	0.01	29.9	16.5	4.2	25.9	Preferred: 27-29 Best juvenile growth: 22-25 Juvenile growth range: 11-30 Min–Max tolerance: 2-30 Spawning, max weekly avg: 17 Embryo max tolerance: 20	Kieffer and Cooke 2009, Edwards et al. 1984, Baker and Heidinger 1996, Sheehan et al. 1994
Dissolved Oxygen	mg/L	10.2	6.0	14.9	9.4	5.9	15.8	Min tolerance: 2.0 Min for successful spawning: 2.6	Knights et al. 1995, Carlson and Herman 1978
pH (field)	pH	7.7	5.9	8.8	7.5	6.7	8.6	Range: 5-8.75 Min tolerance for nesting: 4.7 Min tolerance for hatching: >4.7	Graham 1993, Warren 2009
pH (lab)	pH	7.8	6.5	8.5	7.7	6.9	8.6		
Alkalinity	ppm	42.3	24.4	75	38.3	20.5	52.9	Max tolerance: 900	Carlander 1977
Potassium	mg/L	0.56	0.32	1.1	0.55	0.35	1.1	Max tolerance: 200	Carlander 1977
Sodium	mg/L	3.05	1.56	6.47	3.50	1.99	7.54	Max tolerance: 200	Carlander 1977

Water quality data source: Stantec 2016

*JTU = Jackson Turbidity Units

In South Dakota, the abundance of age-0 Black Crappie and Yellow Perch between years was negatively correlated (Pope et al. 1996b). These differences appeared to be caused by opposite responses to weather conditions, with Black Crappie abundance negatively correlated to precipitation and positively correlated with mean daily temperature difference and mean wind speed, while Yellow Perch had the opposite response.

The presence of carp can sometimes have a detrimental effect on Black Crappie populations with higher carp abundance linked to a lower abundance of Black Crappie (Aday et al. 2009, Egertson and Downing 2004). As carp are known to increase turbidity and decrease aquatic vegetation, the Black Crappie decline was likely a response to the worsening environmental conditions.

The presence of predatory fish can impact Black Crappie population dynamics, but not necessarily in a negative way. In South Dakota, introduction of the predatory Saugeye (female Walleye *Sander vitreus* x male Sauger *S. canadensis*) resulted in improved growth rates and a larger size structure in Black Crappie (Galinat et al. 2002). Saugeye were observed to eat all life stages of Black Crappie, although they did not eat individuals over 20 cm. At high densities, Black Crappie growth rates decrease and the population often becomes stunted, as such, the Saugeye likely reduced the density of Black Crappie, lessening intraspecific competition,

resulting in improved growth. In 4 Wisconsin lakes, Black Bullhead and Yellow Bullhead (*Ameiurus natalis*) were completely removed from the lakes (Sikora et al. 2021). This resulted in the decline of Bluegill and the increase of Black Crappie and Yellow Perch, suggesting bullhead were having a detrimental effect on their survival and recruitment. The community structure shifted from one dominated by Bluegill and bullhead to one dominated by Walleye (*Sander vitreus*), Yellow Perch, and Black Crappie.

3.7 BEHAVIOR AND MOVEMENT

3.7.1 General movement

Black Crappie move around a waterbody in response to their seasonal habit preferences, to track resources, avoid extreme physical conditions, and in response to environmental changes (Warren 2009). At times, these fish can move great distances. In mark-recapture studies in Florida, 38% of recaptured individuals travelled at least 5 km from the point of capture, while 3 individuals travelled over 99 km (Warren 2009). In a series of 16 interconnected lakes in Minnesota, a tagging study over 3 years found that annual emigration rates ranged from 0-92%, with some individuals travelling over 9.5 km from the release lake (Parsons and Reed 2005). In that study, emigration may have been affected by the size of the lake, with more emigration occurring from smaller lakes. Conversely, a tagging study in Manitoba found movement between lakes was infrequent with only 3 of 50 individuals moving to a different lake with one of those individuals having been translocated by a fisherman (Hauger 2020).

3.7.2 Diel movement

Adult and juvenile Black Crappie have opposite daily activity patterns, with juveniles more active during the day (Ellison 1984, Hanson and Qadri 1984) and adults primarily nocturnal (Guy et al. 1992, Helfman 1981). Guy et al. (1992) studied adult Black Crappie movement in a South Dakotan lake and found movement increased from evening to the morning (max 121.5 m/hr) and was lowest during the day (45.1 m/hr).

Overall, adults remained in the mid-lake regions during the day and usually moved towards the shore at night (Warren 2009, Guy et al. 1992). Their movements changed somewhat between the spring and summer, as adult Black Crappie were found in shallower areas during the evening and night in the spring, versus during the day and evening in the summer. In New York, Helfman (1981) found adult Black Crappie formed daytime resting aggregations near anchored floats, or in the water column in deep macrophyte beds. Movements between these resting areas and feeding areas occurred during sunset when the light began to decline rapidly, and during sunrise when the increase in light intensity began to level off.

3.7.3 Seasonal movement

Changes in seasonal Black Crappie activity level appears to be related to spawning. Activity in the spring increases until the spawning season, when it drops off, and then increases again after spawning completes (Parsons 2015, Guy et al. 1992). In South Dakota, adult Black Crappie

movement was positively correlated to barometric pressure in a quadratic relationship, while movement was negatively linearly correlated to wind speed (Guy et al. 1992).

Upon leaving the nest, juvenile Black Crappie spend several weeks in the pelagic zone, starting in deeper waters and gradually moving to shallower areas, before finally returning to the vegetated areas of the littoral zone (Post et al. 1995). They remain in the shallow vegetated areas until the fall when the vegetation dies, at which point they disperse more evenly around the waterbody (Weber and Brown 2012).

During the winter and early spring, Black Crappie tend to move to the deeper areas of the lakes (Hanson et al. 1983), but can still show considerable movement around the waterbody. In the Mississippi River, considerable movement of Black Crappie was noted to and from an ice-covered backwater (Suski and Ridgway 2009), potentially in order to seek improved dissolved oxygen conditions. Black Crappie have been recorded in the wild moving through areas with temperatures $<1^{\circ}\text{C}$ in order to reach areas with improved dissolved oxygen levels (Knights et al. 1995). Under winter conditions in a lab, Black Crappie formed loose clusters of multiple individuals, but not true aggregations (Suski and Ridgway 2009).

3.7.4 Swimming speed

A study by Gaston (2011) found no patterns in critical swimming speed (U_{crit}) during the day, but did find seasonal variations. During the summer, U_{crit} averaged 24.15 ± 10.69 cm/s and was significantly greater than in winter which averaged 15.32 ± 1.14 cm/s. Spring (22.97 ± 2.49 cm/s) and fall (19.63 ± 2.59 cm/s) U_{crit} did not differ significantly from the other months.

Gaston (2011) also tested the effect of increased turbidity on U_{crit} and found a 63% reduction in swim performance at the highest turbidity levels tested (see Section 3.8.1 for additional details).

3.8 PHYSIOLOGICAL TOLERANCES

Black Crappie tolerances for many environmental parameters have been summarized in Tables 5 and 6. These tolerances are discussed in detail below.

3.8.1 Turbidity

It is well known that Black Crappie are intolerant to turbidity. Particularly in waterbodies where both Black and White Crappie are stocked, there appears to be a correlation between increased turbidity, decreased Black Crappie populations, and increased White Crappie populations (Aday et al. 2009, Ellison 1984, Edwards et al. 1982, Carlander 1977). Turbidity has been shown to have a negative impact on recruitment (Mitzner 1991, Edwards et al. 1982) and growth in some populations (Carlander 1977), but not in others (Spier and Heidinger 2002). Edwards et al. (1984) developed Black Crappie suitability indexes for turbidity parameters, including maximum

monthly average turbidity during summer (most suitable range: 0-50 JTU*) and average total dissolved solid (TDS) level during growing season (most suitable range: 100-350 ppm).

Overall, the mechanism(s) behind Black Crappie intolerance to turbidity is not well understood. One common theory is that increased turbidity interferes with Black Crappie's ability to feed (Aday et al. 2009), however, some recent studies have thrown doubt on this. A study in Lake Erie found that Black Crappie displayed a humped shaped response to foraging in turbidity, meaning feeding increased as turbidity increased to a secchi depth of 58 cm and then decreased (Pangle et al. 2012). As well, Andree and Wahl (2019) studied the effects of turbidity on foraging in the lab, conducting feeding experiments with juvenile Black Crappie at 0, 25, and 50 NTU. Overall, the increased turbidity did not impact their ability to forage and actually increased food consumption in all treatments. They did note *Chironomus* consumption decreased slightly in turbid treatments.

There is some evidence that turbidity impacts Black Crappie swimming performance, which could impact their ability to evade predators and increase physiological stress. Gaston (2011) studied differences in critical swimming speed (U_{crit}) and oxygen consumption between Black Crappie and White Crappie at different turbidity levels: 0 JTU (no turbidity), 25 JTU (within optimum range), and 75 JTU (higher than optimum range). For Black Crappie, at 0 JTU mean U_{crit} was 63% higher than at 75 JTU. Comparing the two species, at 0 JTU, U_{crit} was higher for Black Crappie than White Crappie, while at 25 JTU there was no significant difference between the species. At 75 JTU the data was not directly comparable due to some sample variations, but it is notable that several Black Crappie refused to swim while all White Crappie swam. Oxygen consumption was also affected by turbidity, and for both species was significantly higher as turbidity increased. The reason why turbidity decreased swim speed is not clear, but Gaston (2011) theorized it may be due to differences in gill raker physiology between the two species.

Poor performance of Black Crappie in turbid environments may also be due to their preference for complex vegetated habitats. Porreca et al. (2020) found subtle variations in juvenile Black Crappie and White Crappie physiology which appear to be adaptations to improve foraging and predator avoidance in their preferred habitats; complex vegetation for Black Crappie, and open-water for White Crappie. Juvenile Black Crappie had deeper bodies with a short, deep caudal peduncle, while White Crappie has more fusiform bodies and an elongated caudal peduncle. These differences allow Black Crappie to be more maneuverable in dense vegetation, while allowing White Crappie improved swimming in open water and improved predator avoidance in their preferred habitats. Porreca et al. 2020 found that Black Crappie captured significantly faster in open-water habitats than in vegetated ones and their capture avoidance was higher in vegetated habitats, with the opposite results seen for White Crappie. Knowing this, turbidity may have more of an indirect effect on Black Crappie populations, as turbidity is often negatively correlated with aquatic vegetation and Black Crappie survive better in vegetated habitats.

3.8.2 Temperature

For adult Black Crappie, preferred temperatures of 27–29°C were found in lab experiments as well as in a thermal outfall area (Kieffer and Cooke 2009, Edwards et al. 1984). Interestingly, catchability of Black Crappie and most other centrarchids was found to be higher at temperatures higher than their preferred range (Kieffer and Cooke 2009). Optimal temperature for juvenile growth has been reported to be 22–25°C, with no growth occurring below 11°C or above 30°C (Edwards et al. 1984).

Baker and Heidinger (1996) studied age-0 Black Crappie survival using acute and critical thermal maxima (CTmax) exposure tests, and determined their maximum thermal tolerance to be 30°C. In the acute exposure tests for age-0 fish acclimated to 24°C, when suddenly transferred to warmer temperatures, the LT50s ranged from 32–35°C. Using CTmax tests (where fish are slowly warmed over time) for fish acclimated to 24°C CTmax ranged from 33–39°C, while for fish acclimated to 30°C and 32°C all the fish died at or before 40°C. Baker and Heidinger (1996) used these results to develop a predictive model for age-0 Black Crappie for temperatures that resulted in the death of all fish (Equation 6).

$$\text{Death Temperature} = 0.2731T - 0.0596L + 2.8678K + 31.2855 \quad (6)$$

Where:

T = acclimation temperature (°C)

L = total length of the fish (cm)

K = condition factor

The condition factor was calculated based on the following equation (Equation 7).

$$K = \frac{W}{L^3} 100 \quad (7)$$

Where:

K = condition factor

W = wet weight (g)

L = total length (cm)

Acute exposures to high temperatures in the summer can impact growth and cause mortality in fishes. For short (24 hr) exposures in the summer, Brungs and Jones (1977) found that for Black Crappie, the maximum weekly average temperature they can be exposed to and still have successful growth was 27°C. For short exposures in the spawning season, the maximum weekly average temperature for spawning to still occur was 17°C, while the maximum temperature for embryo survival was 20°C.

In Wisconsin, Black Crappie have been reported to overwinter at temperatures of 4.5–7°C (Carlson and Herman 1978), although they can survive at temperatures as low as <1°C for short periods of time (Knights et al. 1995). Sheehan et al. (1994) studied overwintering survival by exposing Black Crappie and other centrarchid YOY to temperatures of either 0°C, 2°C, or 4°C for 40–50 days, and monitoring overall survival. For Black Crappie, 74% died after prolonged

exposure to 0°C, although this was lower than Bluegill (85%) or Largemouth Bass (100%). At 2°C, Black Crappie mortality reduced to 34%, and at 4°C it dropped further to 16%. While Bluegill mortality was higher than Black Crappie at 0°C, it was lower at 2°C (20%) and 4°C (13%).

Cooke et al. (2003) studied the cardiac response to disturbance at low temperatures for several fishes including Black Crappie and White Bass. White Bass are considered a winter-active fish, while Black Crappie are considered intermediately active. Held at temperatures of 3°C ±1°C, Black Crappie had similar cardiac parameters to White Bass, and became exhausted at a similar rate to White Bass, but recovered more slowly afterward.

3.8.3 Dissolved Oxygen

Low dissolved oxygen can have negative impacts on survival, spawning, and behaviour in Black Crappie. Overall, dissolved oxygen levels below 1.4 mg/L can cause mortality in Black Crappie (Edwards et al. 1984) and during winter conditions dissolved oxygen concentrations of 0.4–2.0 mg/L have been lethal (Suski and Ridgway 2009). In low temperatures and dissolved oxygen conditions, once dissolved oxygen levels fall below 2 mg/L, Black Crappie will enter habitats with temperatures below 1°C and increased flow rather than remain in the <2 mg/L area (Knights et al. 1995). Knights et al. (1995) recommended minimum dissolved oxygen concentrations of 2–3 mg/L for survival of overwintering Black Crappie.

Carlson and Herman (1978) looked at the effect of prolonged exposure to low dissolved oxygen over winter on the effect of spawning and behaviour. Black Crappie were exposed to constant dissolved oxygen levels near 2.5, 4.0, 5.5 and 7.0 mg/L over the winter. In the spring, a simulated temperature rise occurred to match typical spring-summer conditions and treatments either continued at the original dissolved oxygen level, or were subjected to diel fluctuations from 0.8 to 1.9 over and under the original dissolved oxygen level. At the lowest fluctuating dissolved oxygen treatment (1.8 to 4.1 mg/L), no spawning occurred and behavioural abnormalities (surface breathing, erratic darting swimming, increased gill ventilation) were seen once water temperatures reached 20°C. All other treatments successfully spawned. Carlson and Herman (1978) concluded that dissolved oxygen concentrations near 2.6 mg/L and above are sufficient to meet the oxygen requirements of mature male Black Crappie.

3.8.4 Salinity

Black Crappie are moderately tolerant of salinity and can survive in brackish waters, although they are rarely found there in Canadian waters (Edwards et al. 1982). In Louisiana, they were found in waters with salinity of up to 2 ppt (Carlander 1977), in 1.32 ppt in the Mississippi River delta, 4.7 ppt in North Carolina (Edwards et al. 1982), and have been occasionally known to enter tidal waters (<5.0 ppt) to feed on small fish and shrimp (Warren 2009).

3.8.5 pH

Black Crappie are also somewhat tolerant of low pH. In New Jersey, Black Crappie were found in systems with pH ranging from just below 5 to around 8.75 with a median slightly above 7 (Graham 1993). In Wisconsin along a bog lake successional gradient, Black Crappie were rare or absent from lakes with pH less than 6 (Warren 2009), while in Maryland Black Crappie were rare in lakes with pH less than 4.9 (Kilian et al. 2009). In a whole lake acidification experiment, Black Crappie were found to nest in pH of 4.7–5.6, however no larvae were observed at the lowest pH (Warren 2009).

Black Crappie can also survive in slightly alkaline entropic water, up to limits of 900 ppm total alkalinity, 250 ppm carbonates, and 200 ppm potassium and sodium (Carlander 1977).

3.8.6 Water velocity

Black Crappie show an aversion to high water velocities. They are absent from streams with gradients >2 m/km and are common in streams with gradients <0.5 m/km (Edwards et al. 1984). Optimum current velocities are <10 cm/s, and they are intolerant of velocities above 60 cm/s (Edwards et al. 1984). Under winter conditions, Black Crappie avoided areas with velocities greater than 1 cm/s, which may be a winter survival adaptation to reduce the need to swim and therefore conserve energy (Knights et al. 1995).

3.8.7 Interacting tolerances

Environmental conditions often interact with each other to produce complex responses in organisms. In Minnesota, winter habitat selection was studied and the interactions between temperature, dissolved oxygen, and water velocity examined (Knights et al. 1995). Above a dissolved oxygen of 2 mg/L, Black Crappie selected areas with temperatures above 1°C and undetectable current. Below a dissolved oxygen of 2 mg/L, they moved into higher dissolved oxygen areas, despite temperatures below 1°C and current velocities of 1 cm/s. Areas with temperatures 1°C and below and current velocities greater than 1 cm/s were avoided. When dissolved oxygen levels were adequate, Black Crappie preferred areas with warmer temperatures.

3.9 DISEASES AND PARASITES

3.9.1 Viral hemorrhagic septicemia (VHS)

Viral Hemorrhagic Septicemia (VHS) is one of the world's most serious fish diseases, infecting over 80 freshwater and marine species across North America (Stepien et al. 2015). An RNA rhabdovirus, VHS is caused by the Viral Hemorrhagic Septicemia Virus (VHSV), and while potentially devastating to fish, is not infective to humans (Bowser 2009). The virus is subject to rapid mutational changes, and is currently classified into four major genotypes, (I, II, III and IV) and ten subtypes (Ia-Ij and Iva-Ivd) (Garver and Hawley 2021). Genotypes I, II, and III are predominately limited to Europe, while genotype IV is found in North America, Iceland, China,

Japan and Korea (Garver and Hawley 2021) (Fig. 9). Within Canada, the virus is found along the coast of British Columbia (subtype IVa), throughout the Laurentian Great Lakes region (subtype IVb), and in the estuarine waters of New Brunswick and Nova Scotia (subtype IVc) (Garver and Hawley 2021).

The especially virulent substrain – IVb – emerged in the Laurentian Great Lakes in 2005 (Stepien et al. 2015), the first time the virus was known to occur in a freshwater environment (Bowser 2009). The Round Goby (*Neogobius melanostomus*) is an invasive fish introduced into the Great Lakes in the 1990s. As it is highly susceptible to the virus, it is suspected that the population growth and expansion of this invasive fish around the Great Lakes helped spread the virus (Stepien et al. 2015). Since its emergence, the VHSv-ICb strain of VHS has caused numerous mortality events across the Great Lakes (with the exception of Lake Superior), in a wide variety of species, including Black Crappie (Stepien et al. 2015). VHS causes a variety of lesions including hemorrhagic ones, as the name suggests. The virus destroys the endothelial cells lining the inside of the interior of the blood vessels causing them to break down and hemorrhage (Bowser 2009). Diagnosis of the presence of VHSV must be based on laboratory testing of infected samples (Bowser 2009).

Species can be more or less susceptible to the different strains. Emmenegger et al. (2013) compared the susceptibility of several species, including Yellow Perch, Rainbow Trout (*Oncorhynchus mykiss*), and Pacific Herring (*Clupea palasii*), to the various strains. Yellow Perch was the most susceptible to all strains, having very high susceptibility (80-100% mortality) to IVa and IVb, and high susceptibility (56-79% mortality) to IVc, when exposed to a low dose of each substrain. Pacific Herring was next most susceptible overall, with very high susceptibility to IVa and high susceptibility to IVb and IVc. Rainbow Trout was the most resilient, with very low susceptibility (0-10% mortality) to both IVa and IVb, and low (11-30% mortality) to IVc.

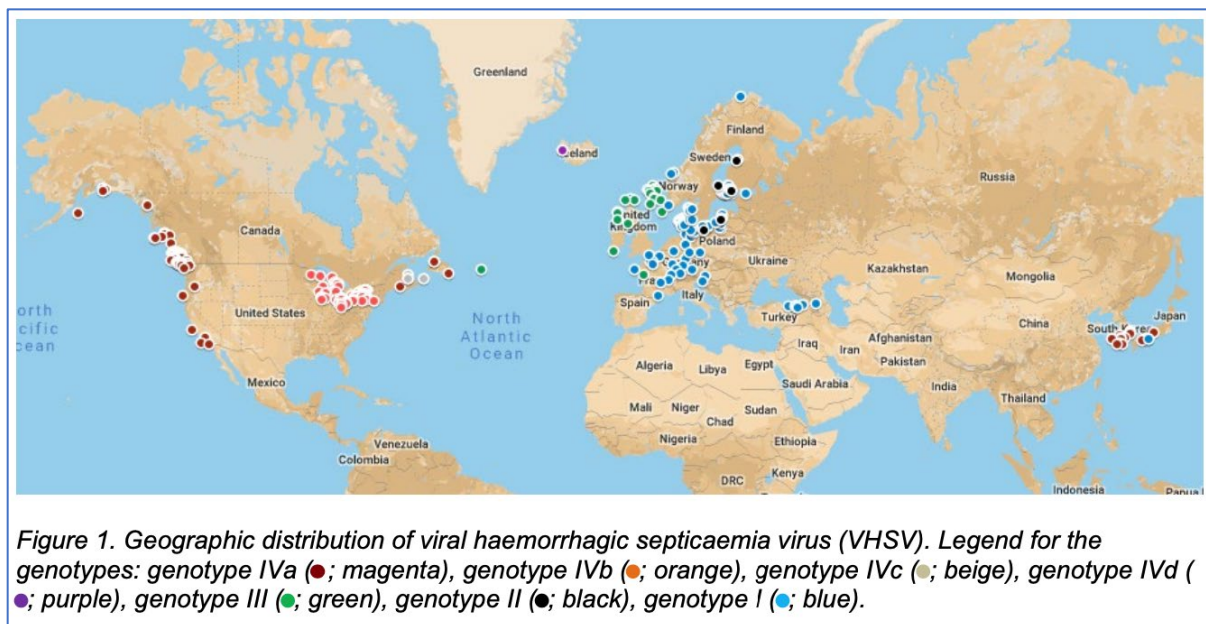


Figure 9. Geographic distribution of viral haemorrhagic septicaemia virus (VHSV). Source: Garver and Hawley 2021.

3.9.2 Parasites

Black Crappie can be host to a wide range of parasites including protozoans, trematodes, cestodes, nematodes, acanthocephalans, leeches, and crustaceans (Scott and Crossman 1973). Fish raised in aquaculture facilities are particularly prone to high parasite burdens due to high fish densities within these facilities (Bader et al. 2017).

Monogeneans are flatworm parasites that infect fish skin and gills, and can be spread directly from fish to fish or indirectly through the environment as they do not have an obligatory intermediate host (Bader et al. 2017). In the wild at low fish densities, monogeneans are often limited, but at high fish densities, they can build up in fish tissues leading to mucus production in the gills impairing oxygen uptake. At high levels of infection, monogeneans can cause over 80% mortality in the infected population (Bader et al. 2017). High levels of infection with the monogenean *Cleidodiscus* in commercially reared juvenile Black Crappie resulted in increased surface gasping and increased mortality events (Bader et al. 2017).

Black Crappie are commonly infected with Black Spot disease, which is caused by infection with the digenetic trematode, *Uvulifer ambloplitis*, also known as black grubs (Lane and Morris 2000). They present as pinhead-sized black spots in the skin, tail base, fins, and muscles and severe infections can cause mechanical damage, hemorrhage, and loss of lipids and body condition (Lane and Morris 2000). The host cycle for this parasite typically starts with the Belted Kingfisher (*Megaceryle a. alcyon*), moving through snails of genus *Planorbella*, before entering its fish hosts (Lane and Morris 2000). Centrarchids and Yellow Perch are the species most commonly affected by Black Spot (Lane and Morris 2000).

Black Crappie is a known host for several mussel species including Mucket (*Actinonaias ligamentina*), Threeridge (*Amblema plicata*), Cylindrical Papershell (*Anodontoidea ferussacianus*), Fatmucket (*Lampsilis siliquoidea*), and is a putative host to Creek Heelsplitter (*Lasmigona compressa*) (Warren 2009).

3.9.3 Bacterial infections

Edwardsiella spp. are a group of bacteria that can cause significant losses in freshwater fishes and has a varied presentation in a range of lesions, often described as bacterial septicaemia (Griffin et al. 2019). In the Channel Catfish (*Ictalurus punctatus*) industry in the United States, *Edwardsiella ictaluri* infections caused the most disease and mortality, followed by the disease Columnaris (Declercq et al. 2013). *Edwardsiella piscicida* was recognized as a distinct organism in 2013 and has since been reported in over 20 economically and recreationally important fish, including Black Crappie (Griffin et al. 2019).

Columnaris is a common infectious bacterial disease of freshwater fish that affects both wild and cultured populations but can be particularly detrimental in fish farms (Mitiku 2018). It is caused by *Flavobacterium columnare* and may result in skin lesions, fin erosion and gill necrosis with a high degree of mortality and in the Channel Catfish industry in the United States can

cause estimated losses of 30 million dollars annually (Declercq et al. 2013). It is spread primarily through the gills, is more effectively spread at high temperatures, and can survive in the environment under the right conditions (Mitiku 2018, Declercq et al. 2013). It is found worldwide in a wide variety of fish including Black Crappie, other centrarchids and salmonids (Mitiku 2018). Concurrent infection with ectoparasites can increase the chance of mortality for fish infected with *F. columnare* (Mitiku 2018).

3.9.4 Testicular Oocytes

The development of testicular oocytes in male fishes - also termed intersex - is a biomarker used to identify fish populations affected by endocrine-disrupting compounds (EDCs) in aquatic systems (Fritts et al. 2018). Potential sources of EDCs include pharmaceuticals, human and animal steroids, and personal hygiene products like shampoo. A study in the Illinois River in 2015 found testicular oocytes in 27% of Black Crappie collected (Fritts et al. 2018).

3.9.5 Black Crappie Sarcoma (BCS)

Black Crappie Sarcoma manifests in the form of a tumor in front of the pelvic fin of Black Crappie and is primarily affecting lake systems in western Wisconsin (Boyd 2019). In addition, lesions also form on the pectoral, anal, and caudal fins. The disease is currently spreading in the Wisconsin region but the cause and modes of transmission are currently unknown. It is not known in other fish species.

4.0 USE BY HUMANS

4.1 RECREATIONAL FISHING

Black Crappie is a very popular panfish as it is relatively easy to catch and has a good flavour (Riso 2011, Warren 2009). In the United States, it has been introduced throughout the country and stocked extensively for recreation and currently supports a large recreational fishery (Quinn and Paukert 2009). In terms of fisheries management, Black and White Crappie catch numbers and angler data are typically aggregated. In 2016 in the United States, 7.8 million anglers spent a total of 107 million angling days fishing for crappie (USFWS 2016). Some anglers have been known to travel over 250 km just to fish for crappie (Riso 2011) and crappie rank among the top 3 most popular species groups for 17 states (Quinn and Paukert 2009). Within Canada, it is a locally popular panfish in the provinces where it currently is found (Quinn and Paukert 2009).

While primarily fished for consumption, there has been a shift towards a more selective harvest attitude for Black Crappie, and catch-and-release and tournament fishing (Hooe 1991) has become more popular in recent years (Quinn and Paukert 2009).

4.2 COMMERCIAL FISHING

Historically, Black Crappie were fished commercially, although that is limited now (Quinn and Paukert 2009). In the United States, commercial fisheries for crappie previously existed in

places like New York, Tennessee, and Florida. Legislation in the 2000s effectively ended commercial fishing of crappie in New York state. The fishery in Tennessee closed in 2002, while the Florida fishery closed in 1981, after harvesting 12,000-19,000 kg and 836,638 kg, respectively at their peaks. In Florida, bycatch of crappie from currently operating commercial fisheries is impacting the local crappie fishery (Dotson et al. 2009), with the exploitation rate for the Black Crappie population estimated at 42% for the recreational fishery and 15% from bycatch in the commercial fishery.

In Canada, limited commercial fishing for Black Crappie occurs under quota systems operated by First Nations peoples (Quinn and Paukert 2009). In Lake Erie, on Long Point Bay the harvest of all centrarchids from the fishery ranged from 6500 to 30,400 kg annually from 1999–2004, the majority of which were sunfish (*Leopomis spp.*). In eastern Lake Ontario, annual catches of Black Crappie ranged from about 4500 to 8000 kg between 1999 and 2009.

4.3 AQUACULTURE

Black Crappie has been a documented aquaculture fish species since at least 1908 and is currently propagated in public and private facilities across the United States (Culpepper and Allen 2016). Approximately 3,238,000 Black Crappie are produced annually by fisheries agencies in 10 out of the 48 states within the continental United States (Culpepper and Allen 2016) for stocking in recreational fisheries (Morris and Clayton 2009). In 2018, crappie aquaculture production yielded \$869,000 (USD) in sales (USDA 2019).

5.0 IMPACTS ASSOCIATED WITH INTRODUCTIONS

5.1 IMPACTS ON PLANKTON AND BENTHIC INVERTEBRATES

Plankton make up the majority of Black Crappie diets for the earliest portion of their lives, of which copepods are typically the largest component. As they grow, Black Crappie add more benthic invertebrates and, eventually, fish to their diets. However, only the largest individuals become fully piscivorous meaning they rely on consuming plankton and/or invertebrates through most, if not all of their lives. Although many groups of plankton and invertebrates are typical in Black Crappie diets across their range, their diets are highly flexible and are often adapted to what is available.

Unfortunately, research related to Black Crappie, plankton, and/or benthic invertebrates is mostly focused on how zooplankton abundance impacts Black Crappie populations and diets (Aday et al. 2009, Bunnell et al. 2003, Allen et al. 1998, Hanson and Qadri 1984) and not the other way around. As such, no direct research looking into the effects of Black Crappie on plankton and benthic invertebrate communities was located.

Given Black Crappie's overall preference for consuming Arthropods, Copepods in particular, any introductions of Black Crappie to a new system will almost certainly have an impact on the local Copepod community, which would presumably increase with the density of the Black Crappie population. Impacts to its other preferred Arthropod prey groups (Chironomids, Cladocerans, Chaoborus, Ostracods, and Daphnia) would also likely occur, although the magnitude of those

impacts would be hard to predict given the variability of Black Crappie diets. Additional direct impacts to other prey groups may occur as different Black Crappie populations and individuals have been shown to have localized prey preferences.

Compared to other piscivorous fish, Black Crappie typically eat more zooplankton and for longer. They also tend to select for smaller prey when compared to their body size (Schael et al. 1991) so could have a greater negative impact on the abundance of the smaller size classes of zooplankton than other similarly sized piscivorous fish.

5.2 IMPACTS ON MUSSELS

According to NatureServe (2022a), of the five mussel species that Black Crappie is known to host (Table 7), all are found in Canada to varying extents with Fatmucket present across most of the country, and Mucket only found in Ontario. Most of these mussel species are considered secure across most of their Canadian range, with Threeridge and Cylindrical Papershell vulnerable in Manitoba and Québec, respectively. Creek Heelsplitter is at risk across most of its range (with the exception of Ontario where it is secure), ranging from critically imperiled in Alberta and some US states to imperiled and vulnerable across the rest of its range.

The expansion of the Black Crappie range may have positive effects on some mussel populations by providing an additional host organism for the mussels. This could be particularly beneficial for some of the at risk mussels, like the Threeridge in Manitoba, and the Cylindrical Papershell in Québec, where Black Crappie are currently not widely distributed. Its potential benefits for the Creek Heelsplitter is less evident, as Black Crappie is currently widely distributed throughout the areas where the mussel is at risk, so further Black Crappie expansion may have not have any effect on the mussels' populations.

Of the mussels Black Crappie is known to host (Table 7), none are found in New Brunswick or in the Saint John River Basin (Martel et al. 2010). Eleven (11) mussel species have been historically recorded in the Saint John River (Stantec 2016), of which 5 species were collected in the vicinity of the Mactaquac Generating Station (MGS) (Dolson-Edge et al. 2019), including Eastern Elliptio (*Elliptio complanata*), Eastern Floater (*Pyganodon cataracta*), Alewife Floater (*Anodonta imbecilis*), Eastern Lampmussel (*Lampsilis radiata*), and Tidewater Mucket (*Leptodea ochracea*). Table 8 summarizes these mussel species and indicates which species have some potential to use Black Crappie as a host, based on their usage of other centrarchids as hosts.

If some of these mussel species were able to use Black Crappie as a host, that could potentially prove beneficial for the mussel species. In particular, both the Yellow Lampmussel (*Lampsilis cariosa*) and Brook Floater (*Alasmidonta varicosa*) are considered special concern within New Brunswick and have the potential to be found in the Saint John River. Both species are known to use other centrarchids as hosts so there is an increased potential for them to find Black Crappie a suitable host.

Table 7. Distribution and conservation status of mussel species known to utilise Black Crappie as a host.

Common Name	Scientific Name	Distribution and Status
Mucket	<i>Actinonaias ligamentina</i>	Ontario (S4)
Threeridge	<i>Amblema plicata</i>	Saskatchewan (SNR), Manitoba (S3), Ontario (S4)
Cylindrical Papershell	<i>Anodontoides ferussacianus</i>	Alberta (SNR), Saskatchewan (SNR), Manitoba (S4), Ontario (S4), Québec (S3)
Fatmucket	<i>Lampsilis siliquoidea</i>	Northwest Territories (S4), British Columbia (SNR), Alberta (S4), Saskatchewan (S5), Manitoba (S5), Ontario (S5), Québec (S4)
Creek Heelsplitter	<i>Lasmigona compressa</i>	Alberta (S1), Saskatchewan (S3), Manitoba (S2), Ontario (S5), Québec (S3), New Brunswick

Source: NatureServe 2022a. SNA = No Status, S1 = Critically imperiled, S2 = Imperiled, S3 = Vulnerable, S4 = Apparently Secure, S5 = Secure

Table 8. Mussel species presence potential in Saint John River and their potential to use Black Crappie as a host.

Common Name	Scientific Name	Mussel Presence		Black Crappie host potential ³	Rationale
		Saint John River ¹	MGS ²		
Dwarf Wedgemussel	<i>Alasmidonta heterodon</i>	Probably extirpated		Low	No known centrarchid hosts
Triangle Floater	<i>Alasmidonta undulata</i>	Yes		Moderate	Pumpkinseed known host
Brook Floater	<i>Alasmidonta varicosa</i>	Unlikely		Moderate	Pumpkinseed known host
Alewife Floater	<i>Anodonta implicata</i>	Yes	Yes	Low	Only clupeid hosts known
Eastern Elliptio	<i>Elliptio complanata</i>	Yes	Yes	Low	No known centrarchid hosts
Yellow Lampmussel	<i>Lampsilis cariosa</i>	Potential		Moderate	Smallmouth Bass known hosts
Eastern Lampmussel	<i>Lampsilis radiata</i>	Yes	Yes	Moderate	Smallmouth Bass and Pumpkinseed known hosts
Tidewater Mucket	<i>Leptodea ochracea</i>	Yes	Yes	Low	No known centrarchid hosts
Eastern Pearlshell	<i>Margaritifera margaritifera</i>	Unlikely		Low	Only Salmonids known as hosts
Eastern Floater	<i>Pyganodon cataracta</i>	Yes	Yes	Moderate	Pumpkinseed known host
Creeper	<i>Strophitus undulatus</i>	Potential		Low	No known centrarchid hosts

1, Stantec 2016; 2, MGS = Mactaquac Generating Station, Source: Dolson-Edge 2019; 3, Given a moderate designation if known hosts included other centrarchids, low if not. Information on known hosts in New Brunswick taken from Martel et al. (2010).

5.3 IMPACTS ON FISH

5.3.1 Predation and competition

Due to the different diet composition of young versus adult Black Crappie, the impacts of Black Crappie on other fish can vary depending upon the life stages being examined. As such, sometimes opposite effects are seen when comparing the impacts of young versus adult Black Crappie. In general terms, younger, planktivorous Black Crappie can compete with other

planktivorous fish, or the planktivorous young of piscivorous fish, for food resources. As Black Crappie diets shift towards piscivory, they can increasingly compete with piscivorous fish for food resources and directly impact smaller fish through predation.

Due to their diverse tastes, Black Crappie diets overlap with a lot of other fish species which could lead to interspecific competition for resources. However, their diets are most consistently similar with Yellow Perch and White Perch (*Morone americana*) (Feiner et al. 2019a, Pelham et al. 2001) and were most significantly different from Walleye (Pelham et al. 2001). Compared to White Perch, diet overlap was most similar between Black Crappie less than 200 mm and all sizes of White Perch (Feiner et al. 2019a).

Research related to the interactions between Black Crappie and forage fish is mostly focused on how forage fish abundance relates to Black Crappie growth and recruitment success, rather than examining the impacts that Black Crappie have on forage fish populations. However, there is still some information that can be gleaned from these studies. In California, Li et al. (1976) studied the impacts of introducing Mississippi Silverside (*Menidia audens*) into a lake on Black and White Crappie populations. Post-introduction, they found a reduction of growth in the first two years of life for both crappie species, presumably due to intraspecific competition for food resources with the silverside. After the first 2 years, growth rates of both crappie species increased to levels higher than pre-silverside introduction once they were large enough to prey upon the silverside. A similar response was seen in a study that introduced smelt to a Black Crappie population, except growth was reduced until the age of 3, and was improved thereafter (Carlander 1977). Unfortunately, while these studies show possible resource competition between young Black Crappie and these forage fish they do not provide information on whether the forage fish populations were negatively impacted by that competition.

In California, as Black Crappie was introduced to its waterbodies, California's only native centrarchid, the Sacramento Perch (*Archoplites interruptus*), declined or disappeared. However, the mechanism behind the decline is unknown (Aday et al. 2009).

Older Black Crappie have been known to predate Yellow Perch, Bluegill, Pumpkinseed, Blackchin Shiner, Golden Shiner, Bluntnose Minnow, Freshwater Drum, Logperch, Largemouth Bass, and Smallmouth Bass. In Iowa for age-1 Black Crappie, Bluegill, Bluntnose Minnow, and to a lesser extent, Yellow Perch, were the most abundant food prey eaten. In Ontario, Yellow Perch made up about ½ to 1/3 of the fish diet in fish up to 240 mm (Keast 1968a). Keast (1968a) noted that Black Crappie shared the same pelagic habitat as the Yellow Perch, while the other species tended to live in deeper habitats, which might account for their predominance in the diet.

Given the direct predation of Yellow Perch by Black Crappie, coupled with the significant diet overlap, introductions of Black Crappie could have a significant negative effect on Yellow Perch. Of the New Brunswick fish species that have been recorded in the Saint John River (Table 9), invading Black Crappie would be most likely to negatively impact Yellow Perch. White Perch may also suffer declines due to diet overlap between the species. Table 9 includes information

on whether Saint John River fish species are a known prey fish or predator for Black Crappie. Known prey fish for Black Crappie have the potential to decline upon Black Crappie introduction, while known predators may benefit from an additional prey fish and help control Black Crappie abundance.

Seven (7) of the fish recorded in or around the mouth of the Saint John River are considered species at risk by SARA and/or COSEWIC (DFO 2019) (Table 9). Of those, there is potential for Black Crappie to negatively impact Redbreast Sunfish (*Lepomis auritus*) as Black Crappie are known to predate the young of other centrarchids (Liao et al. 2002, Pelham et al. 2001, Keast 1968b). It is unlikely that Black Crappie would negatively impact American Plaice (*Hippoglossoides platessoides*) or Winter Skate (*Leucoraja ocellata*) as they are marine species and Black Crappie are rarely found in marine environments (Warren 2009, Edwards et al. 1982, Scott & Crossman 1973). For the remaining four species, Atlantic Salmon (*Salmo salar*), Atlantic Sturgeon (*Acipenser oxyrinchus*), Shortnose Sturgeon (*Acipenser brevirostrum*), and American Eel (*Anguilla rostrata*) potential impacts are unclear as there is no information in the literature on Black Crappie interactions with these species specifically, or salmonids, sturgeons, and eels in general.

5.3.2 Hybridization

The only species that Black Crappie is known to hybridize with in the wild is White Crappie (Bolnick 2009, Hubbs et al. 2004, Auer 1982), reaching frequencies of 29.3 to 54.5% at some sites, although most locations where the species co-occur have few to no hybrids (Bolnick 2009). Black and White Crappie are regularly hybridized as part of aquaculture practices in the United States (Baumhoer and Kelly 2016, Bolnick 2009). While laboratory hybridization of Black Crappie with several other sunfish species is possible, survival of the offspring is typically very low (Carlander 1977).

White Crappie are currently not present in New Brunswick (Gautreau and Curry 2020) so Black Crappie hybridization with other fish species in New Brunswick is highly unlikely.

Table 9. Fish species recorded in the Saint John River and their potential as Black Crappie prey or predator.

Family	Common Name ¹	Scientific Name	Location in Saint John River ²							Black Crappie Prey	Black Crappie Predator	References
			Area 1 ³	Area 2 ³	MGS Above ⁴	MGS Below ⁴	Area 3 ³	Area 4 ³	Mouth ⁵			
Acipenseridae	Atlantic Sturgeon (D) - TH	<i>Acipenser oxyrinchus</i>				x	x	x		Unlikely	Unlikely	M. Gautreau 2023 ⁶
	Shortnose Sturgeon (D) - SC	<i>Acipenser brevirostrum</i>				x	x	x		Unlikely	Unlikely	M. Gautreau 2023 ⁶
Agonidae	Sea Raven (M)	<i>Hemitripterus americanus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Ammodytidae	American Sand Lance(M)	<i>Ammodytes americanus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Anguillidae	American Eel (D) – TH	<i>Anguilla rostrata</i>	h	x	x	x	x	x	MF	Possible	Possible	M. Gautreau 2023 ⁶
Atherinopsidae	Atlantic Silverside (M)	<i>Menidia menidia</i>						h	MF	Likely		Li et al. 1976
Catostomidae	Longnose Sucker	<i>Catostomus catostomus</i>	x	x	x	x	hx	x		Possible		M. Gautreau 2023 ⁶
	White Sucker	<i>Catostomus commersonii</i>	x	x	x	x	x	x		Possible		M. Gautreau 2023 ⁶
Centrarchidae	Largemouth Bass (I)	<i>Micropterus nigricans</i>		x	x	x	x			Yes	Yes	Pelham et al. 2001, Keast 1968b
	Pumpkinseed	<i>Lepomis gibbosus</i>	x	x	x	x	x	x		Yes	Possible	Keast 1968b
	Redbreast Sunfish - SC	<i>Lepomis auritus</i>					x	x		Possible	Possible	Liao et al. 2002, Pelham et al. 2001, Keast 1968b Gautreau & Curry 2012
	Smallmouth Bass (I)	<i>Micropterus dolomieu</i>	x	x	x	x	x	x		Yes	Yes	Pelham et al. 2001, Keast 1968b
Clupeidae	Alewife (Gaspereau) (D)	<i>Alosa pseudoharengus</i>		x	x	x	x	x	MF	Possible		M. Gautreau 2023 ⁶
	American Shad (D)	<i>Alosa sapidissima</i>		hx	x	x	x	h		Yes		Keast 1968b
	Atlantic Herring	<i>Clupea harengus</i>							MF			
	Atlantic Menhaden (M)	<i>Brevoortia tyrannus</i>						h				
	Blueback Herring (D)	<i>Alosa aestivalis</i>		x	x	x	x	x	MF	Possible		M. Gautreau 2023 ⁶
Cottidae	Grubby Sculpin (M)	<i>Myoxocephalus aeneus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
	Longhorn Sculpin (M)	<i>Myoxocephalus octodecemspinosus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
	Shorthorn Sculpin (M)	<i>Myoxocephalus scorpius</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
	Slimy Sculpin	<i>Cottus cognatus</i>	x	x			x	x		Possible		M. Gautreau 2023 ⁶

Table 9 (cont'd). Fish species recorded in the Saint John River and the potential as Black Crappie prey or predator.

Family	Common Name ¹	Scientific Name	Location in Saint John River ²							Black Crappie Prey	Black Crappie Predator	References
			Area 1 ³	Area 2 ³	MGS Above ⁴	MGS Below ⁴	Area 3 ³	Area 4 ³	Mouth ⁵			
Cryptacanthodidae	Wrymouth (M)	<i>Cryptacanthodes maculatus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Esocidae	Chain Pickerel (I)	<i>Esox niger</i>		x	x	x	x	x			Likely	Scott & Crossman 1973
	Muskellunge (I)	<i>Esox masquinongy</i>	x	x	x	x	x	x			Likely	Scott & Crossman 1973
Fundulidae	Banded Killifish	<i>Fundulus diaphanus</i>	x	x	x	x	x	x		Possible		M. Gautreau 2023 ⁶
	Mummichog (M)	<i>Fundulus heteroclitus</i>						x	MF			
Gadidae	Atlantic Tomcod (D) (M)	<i>Microgadus tomcod</i>					x	x	MF			
	Pollock (M)	<i>Pollachius virens</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Gasterosteidae	Blackspotted Stickleback	<i>Gasterosteus wheatlandi</i>						x	F	Possible		M. Gautreau 2023 ⁶
	Brook Stickleback	<i>Culaea inconstans</i>				x	x	x		Unlikely		M. Gautreau 2023 ⁶
	Fourspine Stickleback	<i>Apeltes quadracus</i>		x	x	x	x	x	MF	Possible		M. Gautreau 2023 ⁶
	Ninespine Stickleback	<i>Pungitius pungitius</i>	x	x	x	x	x	x	MF	Possible		M. Gautreau 2023 ⁶
	Threespine Stickleback	<i>Gasterosteus aculeatus</i>	x	x		x	x	x	MF	Possible		M. Gautreau 2023 ⁶
Ictaluridae	Brown Bullhead	<i>Ameiurus nebulosus</i>	x	x	x	x	x	x		Likely	Likely	Sikora et al. 2021, Pelham et al. 2001
Leuciscinae	Blacknose Dace	<i>Rhinichthys atratulus</i>	x	x	x	x	x	x		Likely		M. Gautreau 2023 ⁶
	Blacknose Shiner	<i>Notropis heterolepis</i>	x	x	x		x	x		Likely		M. Gautreau 2023 ⁶
	Common Shiner	<i>Luxilus cornutus</i>	x	x	x	x	x	x		Likely		M. Gautreau 2023 ⁶
	Creek Chub	<i>Semotilus atromaculatus</i>	x	x		x	x	x		Likely		M. Gautreau 2023 ⁶
	Fallfish	<i>Semotilus corporalis</i>	x	x	x	x	x			Likely		M. Gautreau 2023 ⁶
	Fathead Minnow	<i>Pimephales promelas</i>	x	x	x	x	hx			Likely		M. Gautreau 2023 ⁶
	Finescale Dace	<i>Chrosomus neogaeus</i>	x	x	x		x			Likely		M. Gautreau 2023 ⁶
	Golden Shiner	<i>Notemigonus crysoleucas</i>	x	x	x	x	x	x		Yes		Keast 1968b
	Lake Chub	<i>Couesius plumbeus</i>	x	x	x	x	x			Likely		M. Gautreau 2023 ⁶
	Northern Redbelly Dace	<i>Chrosomus eos</i>	x	x	x	x	hx	x		Likely		M. Gautreau 2023 ⁶
	Pearl Dace	<i>Semotilus nachtriebi</i>	x	x			hx			Likely		M. Gautreau 2023 ⁶
Lophiidae	Monkfish (M) (Goosefish)	<i>Lophius americanus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Lotidae	Burbot	<i>Lota lota</i>	x	x	x	x	x	x		Unlikely		M. Gautreau 2023 ⁶

Table 9 (cont'd). Fish species recorded in the Saint John River and the potential as Black Crappie prey or predator.

Family	Common Name ¹	Scientific Name	Location in Saint John River ²							Black Crappie Prey	Black Crappie Predator	References
			Area 1 ³	Area 2 ³	MGS Above ⁴	MGS Below ⁴	Area 3 ³	Area 4 ³	Mouth ⁵			
Merlucciidae	Silver Hake (M)	<i>Merluccius bilinearis</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Moronidae	Striped Bass (D)	<i>Morone saxatilis</i>		x	x	x	x	x	MF			
	White Perch	<i>Morone americana</i>		x	x	x	x	x	x	Likely		M. Gautreau 2023 ⁶
Osmeridae	Rainbow Smelt (D)	<i>Osmerus mordax</i>	x	x	x	x	x	x	MF	Yes		Carlander 1977
Percidae	Yellow Perch	<i>Perca flavescens</i>	x	x	x	x	x	x		Yes		Liao et al. 2002, Pelham et al, 2001, Keast 1968b
Petromyzontidae	Sea Lamprey (D)	<i>Petromyzon marinus</i>		h		x	x	x	MF	Possible		M. Gautreau 2023 ⁶
Pholidae	Rock Gunnel (M)	<i>Pholis gunnellus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Phycidae	White Hake (M)	<i>Urophycis tenuis</i>						x	MF	Unlikely		M. Gautreau 2023 ⁶
Pleuronectidae	American Plaice - TH (M)	<i>Hippoglossoides platessoides</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
	Smooth Flounder (M)	<i>Liopsetta putnami</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
	Winter Flounder (M)	<i>Pseudopleuronectes americanus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
	Yellowtail Flounder (M)	<i>Myxopsetta ferruginea</i>						h	F	Unlikely		M. Gautreau 2023 ⁶
Rajidae	Winter Skate - EN (M)	<i>Leucoraja ocellata</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Salmonidae												
	Atlantic Salmon (D) - EN	<i>Salmo salar</i>	h	x	x	x	x	x		Possible	Possible	M. Gautreau 2023 ⁶
	Brook Trout (D)	<i>Salvelinus fontinalis</i>	x	x	x	x	x	x		Possible	Possible	M. Gautreau 2023 ⁶
	Brown Trout (I)	<i>Salmo trutta</i>		x	x	x	x	x		Possible	Possible	M. Gautreau 2023 ⁶
	Lake Trout	<i>Salvelinus namaycush</i>	hx	x			h					
	Lake Whitefish	<i>Coregonus clupeaformis</i>	x	h	x	x	x	h				
	Rainbow Trout (I)	<i>Oncorhynchus mykiss</i>	x	x	x	x	x	x				
	Round Whitefish	<i>Prosopium cylindraceum</i>	x	x	x							

Table 9 (cont'd). Fish species recorded in the Saint John River and the potential as Black Crappie prey or predator.

Family	Common Name ¹	Scientific Name	Location in Saint John River ²							Black Crappie Prey	Black Crappie Predator	References
			Area 1 ³	Area 2 ³	MGS Above ⁴	MGS Below ⁴	Area 3 ³	Area 4 ³	Mouth ⁵			
Scophthalmidae	Windowpane (M)	<i>Scophthalmus aquosus</i>	x	x			x	x	M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Squalidae	Spiny Dogfish (M)	<i>Squalus acanthias</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Syngnathidae	Northern Pipefish (M)	<i>Syngnathus fuscus</i>							M	Unlikely	Unlikely	Warren 2009, Edwards et al. 1982, Scott & Crossman 1973
Umbridae	Central Mudminnow (I)	<i>Umbra limi</i>	x	x	x	x	x	x		Possible		M. Gautreau 2023 ⁶

1, (D) = Diadromous species, (M) = Marine species, (I) = Non-native introduced species, EN = endangered, TH = Threatened, SC = Special Concern (DFO 2019)

2, Locations in Saint John River include: Area 1 = Headwaters to Grand Falls, Area 2 = Grand Falls to Mactaquac Generating Station, MGS above = Above Mactaquac Generating Station, MGS below = Below Mactaquac Generating Station, Area 3 = Mactaquac Generating Station to Long Reach (Oak Point), Area 4 = Long Reach (Oak Point) to Saint John Harbour, Mouth = Mouth of Saint John River and Estuary.

3, x = collected in the location in the 21st century, h = historic records (prior to 1973) (CRI et al. 2011) (Gautreau & Curry 2020).

4, Data collected 2015-2017 (Wegscheider et al. 2020, Dolson-Edge et al. 2019). And/or data used to make distribution maps. (Gautreau and Curry 2020)

5, Data from papers published in 2007 (CRI et al. 2011). M = caught in marine environment only, MF = marine and freshwater, F = freshwater only

6, Mark Gautreau, personal communications February 2023.

6.0 REFERENCES

- Aday, D. D., Parkos, J. J., & Wahl, D. H. (2009). Population and community ecology of Centrarchidae. In S. J. Cooke & D. P. Philipp (Eds.), *Centrarchid Fishes* (pp. 134–164). Wiley-Blackwell. <https://onlinelibrary.wiley.com/doi/10.1002/9781444316032.ch6>
- Allen, M. S., Hoyer, M. V., & Canfield Jr., D. E. (1998). Factors related to Black Crappie occurrence, density, and growth in Florida lakes. *North American Journal of Fisheries Management*, 18, 864–871.
- Andree, S. R., & Wahl, D. H. (2019). Effects of turbidity on foraging of juvenile black and white crappies. *Ecology of Freshwater Fish*, 28(1), 123–131. <https://doi.org/10.1111/eff.12436>
- Aronow, S. (1982). Shoreline development ratio. In M. Schwartz, *Beaches and Coastal Geology* (pp. 754–755). Springer US. https://doi.org/10.1007/0-387-30843-1_417
- Auer, N. A. (Ed.). (1982). *Identification of larval fishes of the Great Lakes Basin with emphasis on the Lake Michigan drainage*. (No. 82–3; Great Lakes Fishery Commission Special Publication, p. 744 pp.). Great Lakes Fishery Commission.
- Bader, C., Jesudoss Chelladurai, J., Thompson, K., Starling, D., & Brewer, M. T. (2017). Outbreak of *Cleidodiscus* in juvenile black crappies (*Pomoxis nigromaculatus*) and bath treatment with praziquantel. *Journal of Fish Diseases*, 40(11), 1737–1739. <https://doi.org/10.1111/jfd.12640>
- Baker, S. C., & Heidinger, R. C. (1996). Upper lethal temperature tolerance of fingerling black crappie. *Journal of Fish Biology*, 48(6), 1123–1129. <https://doi.org/10.1006/jfbi.1996.0115>
- Baker, S. C., & Heidinger, R. C. (1994). Individual and relative fecundity of Black Crappie (*Pomoxis nigromaculatus*) in Baldwin Cooling Pond. *Transactions of the Illinois State Academy of Science*, 87(3 and 4), 145–150. <https://ilacadofsci.com/wp-content/uploads/2013/08/087-15MS9313-print.pdf>
- Barwick, D. H., & Lorenzen, W. E. (1984). Growth responses of fish to changing environmental conditions in a South Carolina cooling reservoir. *Environmental Biology of Fishes*, 10(4), 271–279. <https://doi.org/10.1007/BF00001480>
- Baumhoer, B. M., & Kelly, A. M. (2016). Survival, age-0 abundance, and growth of Black Crappie and hybrid Crappie in 0.1-ha earthen ponds. *North American Journal of Fisheries Management*, 36(3), 447–451. <https://doi.org/10.1080/02755947.2015.1135215>
- bite-me7. (2015, November 30). *Re: Crappies and Bluegills [Online forum post]*. [Iceshanty, Ice Fishing Community, Canada, Ice Fishing Saskatchewan.]. Iceshanty. https://www.iceshanty.com/ice_fishing/index.php?topic=320676.0
- Bolnick, D. I. (2009). Hybridization and speciation in Centrarchids. In S. J. Cooke & D. P. Philipp (Eds.), *Centrarchid Fishes* (pp. 39–69). Wiley-Blackwell. <https://onlinelibrary.wiley.com/doi/10.1002/9781444316032.ch2>
- Boucher, D. (2016, February 2). Illegal fish stockings threaten Maine lakes and rivers [Maine Department of Inland Fisheries and Wildlife]. Fishing Northeast. <https://fishingnortheast.net/national-fishing-news/illegal-fish-stockings-threaten-maine-lakes-and-rivers/>
- Bowser, P. R. (2009). Fish diseases: Viral Hemorrhagic Septicemia (VHS) (Northeastern Regional Aquaculture Center No. 201–2009; NRAC Publication, p. 7). University of Maryland. <http://agrillife.org/fisheries2/files/2013/09/NRAC-Publication-No.-201-2009-%E2%80%93Fish-Diseases-Viral-Hemorrhagic-Septicemia-VHS1.pdf>
- Boyd, K. (2019). Black Crappie Sarcoma: Searching for a piece of the puzzle. *The FASEB Journal*, 33(S1), 475.1. https://doi.org/10.1096/fasebj.2019.33.1_supplement.475.1

- Brungs, W. A., & Jones, B. R. (1977). *Temperature criteria for freshwater fish: Protocol and procedures*. (EPA-600/3-77-061; Ecological Research Series, p. 139 pp.). U.S. Environmental Protection Agency, Environmental Research Lab.
- Bunnell, D. B., González, M. J., & Stein, R. A. (2003). Zooplankton biomass enhances growth, but not survival, of first-feeding *Pomoxis* spp. larvae. *Canadian Journal of Fisheries and Aquatic Sciences*, 60(11), 1314–1323. <https://doi.org/10.1139/f03-112>
- CABI. (2022). *Pomoxis nigromaculatus* (black crappie). [Wallingford, UK: CAB International]. Invasive Species Compendium. <https://www.cabi.org/isc/datasheet/68536#tosummaryOfInvasiveness>
- Canadian Rivers Institute (CRI), Kidd, S. D., Curry, R. A., & Munkittrick, K. R. (2011). *The Saint John River: A State of the Environment Report ; a publication of the Canadian Rivers Institute celebrating 10 years of science*. Canadian Rivers Institute, UNB. https://can01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.unb.ca%2Fresearch%2Finstitutes%2Fcri%2F_resources%2Fpdfs%2Fcriday2011%2Fcri_sjr_soe_final.pdf&data=04%7C01%7Cjennifer.powell%40mail.utoronto.ca%7C79ea026f491f43a7a67108d9dabf42cc%7C78aac2262f034b4d9037b46d56c55210%7C0%7C0%7C637781338377493609%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzliLCJBTiI6IjEhaWwiLCJXVCi6Mn0%3D%7C3000&sdata=WUObO9%2FFrFn2dlfD3wq0Vrnp5sfd5FLFPe%2F9pG5Nzju40%3D&reserved=0
- Carl, G. C., & Guiguet, C. J. (1958). Alien species in British Columbia: Historical records. In B. Klinkenberg (Ed.), *E-Fauna BC: Electronic Atlas of the Fauna of British Columbia*. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia. <https://ibis.geog.ubc.ca/biodiversity/efauna/AlienSpeciesinBritishColumbiaHistoricalRecords.html#FishFrogs>
- Carlander, K. D. (1977). *Handbook of freshwater fishery biology* (3d ed.). Iowa State University Press.
- Carlson, A. R., & Herman, L. J. (1978). Effect of long-term reduction and diel fluctuation in dissolved oxygen on spawning of Black Crappie, *Pomoxis nigromaculatus*. *Transactions of the American Fisheries Society*, 107(5), 742–746. [https://doi.org/10.1577/1548-8659\(1978\)107<742:EOLRAD>2.0.CO;2](https://doi.org/10.1577/1548-8659(1978)107<742:EOLRAD>2.0.CO;2)
- Colwell, A. E., & Schaefer, C. H. (1980). Diets of *Ictalurus nebulosus* and *Pomoxis nigromaculatus* altered by diflubenzuron. *Canadian Journal of Fisheries and Aquatic Sciences*, 37(4), 632–639. <https://doi.org/10.1139/f80-079>
- Cooke, S. J., Grant, E. C., Schreer, J. F., Philipp, D. P., & Devries, A. L. (2003). Low temperature cardiac response to exhaustive exercise in fish with different levels of winter quiescence. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 134(1), 157–165. [https://doi.org/10.1016/S1095-6433\(02\)00240-4](https://doi.org/10.1016/S1095-6433(02)00240-4)
- Cooke, S., & Philipp, D. P. (Eds.). (2009). *Centrarchid fishes: Diversity, biology, and conservation*. Wiley-Blackwell
- Culpepper, C. M., & Allen, P. J. (2016). Aquaculture techniques for Crappie, *Pomoxis* spp., culture. *Journal of the World Aquaculture Society*, 47(3), 314–326. <https://doi.org/10.1111/jwas.12283>
- DeBoer, J. A., Pope, K. L., & Koupal, K. D. (2013). Environmental factors regulating the recruitment of walleye *Sander vitreus* and white bass *Morone chrysops* in irrigation reservoirs. *Ecology of Freshwater Fish*, 22(1), 43–54. <https://doi.org/10.1111/eff.12000>
- Declercq, A. M., Haesebrouck, F., Van den Broeck, W., Bossier, P., & Decostere, A. (2013). Columnaris disease in fish: A review with emphasis on bacterium-host interactions. *Veterinary Research*, 44(1), 27. <https://doi.org/10.1186/1297-9716-44-27>
- DeRoche, S., & Foye, R. (1954). First record of the Black Crappie, *Pomoxis nigromaculatus*, in Maine. *Copeia*, 1954(1), 75. <https://doi.org/10.2307/1440658>
- DFO. (2019). Search Aquatic Species at Risk. Aquatic Species at Risk. Accessed on: 2022-03-17 <https://www.dfo-mpo.gc.ca/species-especes/sara-lep/identify-eng.html?province=New%20Brunswick#speciesTable>

- Dolson-Edge, R., Bruce, M., Samways, K., Gautreau, M., & Curry, R. A. (2019). *Baseline biological conditions in the Saint John River* (No. 2019–066; Mactaquac Aquatic Ecosystem Study, p. 112). Canadian Rivers Institute, University of New Brunswick.
- Dotson, J. R., Allen, M. S., Johnson, W. E., & Benton, J. (2009). Impacts of commercial gill-net bycatch and recreational fishing on a Florida Black Crappie population. *North American Journal of Fisheries Management*, 29(5), 1454–1465. <https://doi.org/10.1577/M08-137.1>
- Dubuc, R. A., & Devries, D. R. (2002). An exploration of factors influencing crappie early life history in three Alabama impoundments. *Transactions of the American Fisheries Society*, 131(3), 476–491. [https://doi.org/10.1577/1548-8659\(2002\)131<0476:AEOfIC>2.0.CO;2](https://doi.org/10.1577/1548-8659(2002)131<0476:AEOfIC>2.0.CO;2)
- Edwards, E. A., Krieger, D. A., Bacteller, M., & Maughan, O. E. (1982). *Habitat suitability index models: Black Crappie*. (FWS/OBS-82/10.6; p. 26 pp.). U.S.D.I. Fish and Wildlife Service.
- Egertson, C. J., & Downing, J. A. (2004). Relationship of fish catch and composition to water quality in a suite of agriculturally eutrophic lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 61, 1784–1796. <https://doi.org/10.1139/F04-109>
- Ellison, D. G. (1984). Trophic dynamics of a Nebraska Black Crappie and White Crappie population. *North American Journal of Fisheries Management*, 4(4A), 355–364. [https://doi.org/10.1577/1548-8659\(1984\)4<355:TDOANB>2.0.CO;2](https://doi.org/10.1577/1548-8659(1984)4<355:TDOANB>2.0.CO;2)
- Emmenegger, E., Moon, C., Hershberger, P., & Kurath, G. (2013). Virulence of viral hemorrhagic septicemia virus (VHSV) genotypes Ia, IVa, IVb, and IVc in five fish species. *Diseases of Aquatic Organisms*, 107(2), 99–111. <https://doi.org/10.3354/dao02671>
- Enns, D. (2022). Can Crappie Be Used as Bait? *Fishin Money- Fishing Tips*. <https://fishinmoney.com/can-crappie-be-used-as-bait/>
- Feiner, Z. S., Brey, M. K., & Burgett, C. (2019a). Consistently high trophic overlap between invasive White Perch and native Black Crappies in southeastern reservoirs. *North American Journal of Fisheries Management*, 39(1), 135–149. <https://doi.org/10.1002/nafm.10256>
- Feiner, Z. S., Coulter, D. P., Linn, M. D., & Höök, T. O. (2019b). A question of scale: Weak evidence for broad regional synchrony in fish year-class strength within or among species in inland lakes. *Fisheries Research*, 214, 45–55. <https://doi.org/10.1016/j.fishres.2019.01.025>
- Finigan, P. A., Mandrak, N. E., & Tufts, B. L. (2018). Large-scale changes in the littoral fish communities of lakes in southeastern Ontario, Canada. *Canadian Journal of Zoology*, 96(7), 753–759. <https://doi.org/10.1139/cjz-2017-0080>
- Follett, W. I. (1960). The fresh-water fishes – their origins and affinities. *Systematic Zoology*, 9(3/4), 212. <https://doi.org/10.2307/2411968>
- Food and Agriculture Organization of the United Nations (FAO). (2022). *Fisheries and Aquaculture—National Aquaculture Sector Overview—Morocco* [Text by: Abdellatif, O. and El-Ahdal, M. Fisheries and Aquaculture Division [online]. Rome.]. Food and Agriculture Organization of the United Nations. <https://www.fao.org/fishery/en/countrysector/ma/en>
- Frale, B. (2019). *SIO Marine Vertebrate Collection. Version 1.7. Occurrence dataset*. Scripps Institution of Oceanography; Accessed via GBIF.org on 2022-01-21. <https://www.gbif.org/occurrence/1423479208>. <https://doi.org/10.15468/ad1ovc>
- Fricke, R., Eschmeyer, W., & Fong, J. D. (2020). *Eschmeyer's Catalog of Fishes—Genera/Species by Family/Subfamily*. California Academy of Sciences. <https://researcharchive.calacademy.org/research/ichthyology/catalog/SpeciesByFamily.asp#Table2>
- Fritts, M. W., Fritts, A. K., Pendleton, R. M., VanMiddlesworth, T. D., Solomon, L. E., DeBoer, J. A., & Casper, A. F. (2018). Survey of intersex (testicular oocytes) in Black Crappie collected from the Illinois River Waterway. *Journal of Fish and Wildlife Management*, 9(2), 659–665. <https://doi.org/10.3996/032018-JFWM-021>

- Froese, R., & Torres, A. G. (2022). *Pomoxis nigromaculatus*, Black crappie. FishBase. <https://www.fishbase.de/Summary/SpeciesSummary.php?ID=3388&AT=black+crappie>
- Galinat, G. F., Willis, D. W., Blackwell, B. G., & Hubers, M. J. (2002). Influence of a Saugeye (Sauger × Walleye) introduction program on the Black Crappie population in Richmond Lake, South Dakota. *North American Journal of Fisheries Management*, 22, 1416–1424. [https://doi.org/10.1577/1548-8675\(2002\)022<1416:IOASSW>2.0.CO;2](https://doi.org/10.1577/1548-8675(2002)022<1416:IOASSW>2.0.CO;2)
- Garver, K. A., & Hawley, L. M. (2021). *Characterization of viral haemorrhagic septicaemia virus (VHSV) to inform pathogen transfer risk assessments in British Columbia* (Research Document No. 2020/064; Canadian Science Advisory Secretariat, p. 29). Fisheries and Oceans Canada.
- Gaston, C. J. (2011). *The effects of seasonal changes and turbidity on swimming performance in White Crappie Pomoxis annularis and Black Crappie Pomoxis nigromaculatus*. [Masters of Science]. University of Mississippi.
- Gautreau, M.D., B. Wallace, and R.A. Curry. (2018). *Fish Community in the Mactaquac Reservoir: 2016-2017*. Mactaquac Aquatic Ecosystem Study Report Series 2018-024. Canadian Rivers Institute, University of New Brunswick, 31 p.
- Gautreau, M.D. and R.A. Curry. (2020). *Inland fishes of New Brunswick*. Canadian Rivers Institute, 208 Pages
- Gautreau, M.D. and R.A. Curry.(2012) *Ecology and status of the Redbreast Sunfish, Lepomis auratus, in Yoho Lake, New Brunswick*, *Northeastern Naturalist*, 19(4), pp.653-664.
- Gouvernement du Québec (GQ). (2012). *Crappet*. Grand dictionnaire terminologique. https://gdt.oqlf.gouv.qc.ca/ficheOqlf.aspx?Id_Fiche=26556630
- Graham, J. H. (1993). Species diversity of fishes in naturally acidic lakes in New Jersey. *Transactions of the American Fisheries Society*, 122(6), 1043–1057. [https://doi.org/10.1577/1548-8659\(1993\)122<1043:SDOFIN>2.3.CO;2](https://doi.org/10.1577/1548-8659(1993)122<1043:SDOFIN>2.3.CO;2)
- Griffin, M. J., Petty, B. D., Ware, C., & Fogelson, S. B. (2019). Recovery and confirmation of *Edwardsiella piscicida* from a black crappie *Pomoxis nigromaculatus* (Lesueur, 1829). *Journal of Fish Diseases*, 42(10), 1457–1461. <https://doi.org/10.1111/jfd.13056>
- Guy, C. S., Neumann, R. M., & Willis, D. W. (1992). Movement patterns of adult Black Crappie, *Pomoxis nigromaculatus*, in Brant Lake, South Dakota. *Journal of Freshwater Ecology*, 7(2), 137–147. <https://doi.org/10.1080/02705060.1992.9664679>
- Guy, C. S., & Willis, D. W. (1995). Population characteristics of Black Crappies in South Dakota waters: A case for ecosystem-specific management. *North American Journal of Fisheries Management*, 15(4), 754–765. [https://doi.org/10.1577/1548-8675\(1995\)015<0754:PCOBCI>2.3.CO;2](https://doi.org/10.1577/1548-8675(1995)015<0754:PCOBCI>2.3.CO;2)
- Hanson, D. A., Belonger, B. J., & Schoenike, D. L. (1983). Evaluation of a mechanical population reduction of Black Crappie and Black Bullheads in a small Wisconsin lake. *North American Journal of Fisheries Management*, 3(1), 41–47. [https://doi.org/10.1577/1548-8659\(1983\)3<41:EOAMPR>2.0.CO;2](https://doi.org/10.1577/1548-8659(1983)3<41:EOAMPR>2.0.CO;2)
- Hanson, J. M., & Qadri, S. U. (1984). Feeding ecology of age 0 pumpkinseed (*Lepomis gibbosus*) and black crappie (*Pomoxis nigromaculatus*) in the Ottawa River. *Canadian Journal of Zoology*, 62(4), 613–621. <https://doi.org/10.1139/z84-090>
- Hauger, M. (2020). *Investigating Black Crappie (Pomoxis nigromaculatus) populations using age and growth data in Whiteshell Provincial Park, Manitoba* [Master of Science, University of Manitoba]. <https://mspace.lib.umanitoba.ca/xmlui/handle/1993/35067>
- Helfman, G. S. (1981). Twilight activities and temporal structure in a freshwater fish community. *Canadian Journal of Fisheries and Aquatic Sciences*, 38(11), 1405–1420. <https://doi.org/10.1139/f81-187>

- Hooe, M. L. (1991). Crappie biology and management. *North American Journal of Fisheries Management*, 11(4), 483–484. <https://doi.org/10.1577/1548-8675-11.4.483>
- Howell, J. M., Weber, M. J., & Brown, M. L. (2014). Evaluation of trophic niche overlap between native fishes and young-of-the-year Common Carp. *The American Midland Naturalist*, 172(1), 91–106. <https://doi.org/10.1674/0003-0031-172.1.91>
- Hubbs, C. L., Lagler, K. F., & Smith, G. R. (2004). *Fishes of the Great Lakes region* (Rev. ed). University of Michigan Press.
- iNaturalist. (2022). *Observaciones: Mojarra negra*. NaturaLista Mexico. <https://www.naturalista.mx/observations>
- Isermann, D. A., Thompson, A. L., & Talmage, P. J. (2010). Comparisons of sex-specific growth and weight–length relationships in Minnesota Black Crappie populations. *North American Journal of Fisheries Management*, 30(2), 354–360. <https://doi.org/10.1577/M08-151.1>
- Jackson, J. J., & Hurley, K. L. (2005). Relative growth of White Crappie and Black Crappie in the United States. *Journal of Freshwater Ecology*, 20(3), 461–467. <https://doi.org/10.1080/02705060.2005.9664761>
- Keast, A. (1968a). Feeding biology of the Black Crappie, *Pomoxis nigromaculatus*. *Journal of the Fisheries Research Board of Canada*, 25(2), 285–297. <https://doi.org/10.1139/f68-024>
- Keast, A. (1968b). Feeding of some Great Lakes fishes at low temperatures. *Journal of the Fisheries Research Board of Canada*, 25(6), 1199–1218. <https://doi.org/10.1139/f68-105>
- Kieffer, J. D., & Cooke, S. J. (2009). Physiology and organismal performance of Centrarchids. In S. J. Cooke & D. P. Philipp (Eds.), *Centrarchid Fishes* (pp. 207–263). Wiley-Blackwell. <https://onlinelibrary.wiley.com/doi/10.1002/9781444316032.ch8>
- Kilian, J. V., Stranko, S. A., Raesly, R. L., Becker, A. J., & Ciccotto, P. (2009). *Enneacanthus chaetodon* (Blackbanded Sunfish): An imperiled element of Maryland's coastal plain ichthyofauna. *Southeastern Naturalist*, 8(2), 267–276. <https://doi.org/10.1656/058.008.0206>
- Knights, B. C., Johnson, B. L., & Sandheinrich, M. B. (1995). Responses of Bluegills and Black Crappies to dissolved oxygen, temperature, and current in backwater lakes of the Upper Mississippi River during winter. *North American Journal of Fisheries Management*, 15(2), 390–399. [https://doi.org/10.1577/1548-8675\(1995\)015<0390:ROBABC>2.3.CO;2](https://doi.org/10.1577/1548-8675(1995)015<0390:ROBABC>2.3.CO;2)
- Lane, R. L., & Morris, J. E. (2000). Biology, prevention, and effects of common grubs (digenetic trematodes) in freshwater fish (No. 115; Technical Bulletin Series, p. 7). USDA Cooperative State Research, Education and Extension Service. <https://www.ncrac.org/files/biblio/TB115.pdf>
- Langhorne, A. L., Neufeld, M., Hoar, G., Bourhis, V., Fernet, D. A., & Minns, C. K. (2001). *Life history characteristics of freshwater fishes occurring in Manitoba, Saskatchewan, and Alberta, with major emphasis on lake habitat requirements* (No. 2579; Canadian Manuscript Report of Fisheries and Aquatic Sciences, p. 182).
- Li, H. W., Moyle, P. B., & Garrett, R. L. (1976). Effect of the introduction of the Mississippi Silverside (*Menidia audens*) on the growth of Black Crappie (*Pomoxis nigromaculatus*) and White Crappie (*P. annularis*) in Clear Lake, California. *Transactions of the American Fisheries Society*, 105(3), 404–408. [https://doi.org/10.1577/1548-8659\(1976\)105<404:EOTIOT>2.0.CO;2](https://doi.org/10.1577/1548-8659(1976)105<404:EOTIOT>2.0.CO;2)
- Liao, H., Pierce, C. L., & Larscheid, J. G. (2002). Diet dynamics of the adult piscivorous fish community in Spirit Lake, Iowa, USA 1995-1997. *Ecology of Freshwater Fish*, 11(3), 178–189. <https://doi.org/10.1034/j.1600-0633.2002.00015.x>
- Litvak, M. K., & Mandrak, N. E. (1993). Ecology of freshwater baitfish use in Canada and the United States. *Fisheries*, 18(12), 6–13. [https://doi.org/10.1577/1548-8446\(1993\)018<0006:EOFBU>2.0.CO;2](https://doi.org/10.1577/1548-8446(1993)018<0006:EOFBU>2.0.CO;2)

- Lucas, J. (2002). *Minor sportfish management plan*. Department of Inland Fisheries and Wildlife Division of Fisheries and Hatcheries. <https://www.maine.gov/ifw/docs/strategic-management-plans/minorsportfish.pdf>
- Maceina, M. J. (2003). Verification of the influence of hydrologic factors on crappie recruitment in Alabama reservoirs. *North American Journal of Fisheries Management*, 23, 470–480.
- Macías García, C. D. J. (2021). *Distribución de peces dulceacuícolas introducidos en las cuencas del México central, con especial atención a las localidades dentro del área de distribución de los peces endémicos de la familia Goodeidae. Occurrence dataset*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO); Accessed via GBIF.org on 2022-01-21. <https://www.gbif.org/occurrence/1893274400>. <https://doi.org/10.15468/kcz3z0>
- Mandrak, N. E., Cudmore, B., & Chapman, P. M. (2011). *National detailed-level risk assessment guidelines: Assessing the biological risk of aquatic invasive species in Canada*. (Research Document No. 2011/092; Canadian Science Advisory Secretariat, p. 23). Fisheries and Oceans Canada. <https://waves-vagues.dfo-mpo.gc.ca/Library/345462.pdf>
- Mandrak, N. E., Curry, A., Dumont, P., Holm, E., Reist, J., & Watkinson, D. (in press). *Atlas of the Freshwater Fishes of Canada*. University of Toronto Press.
- Martel, A. L., McAlpine, D. F., Madill, J. B., Sabine, D. L., Paquet, A., Pulsifer, M. D., & Elderkin, M. F. (2010). Freshwater mussels (Bivalvia: Margaritiferidae, Unionidae) of the Atlantic Maritime Ecozone. In D. F. McAlpine & I. M. Smith (Eds.), *Assessment of Species Diversity in the Atlantic Maritime Ecozone* (pp. 551–598). NRC Research Press. <https://www.nbm-mnb.ca/wp-content/uploads/2018/06/AMEChapter27Freshwatermussels.pdf>
- Matthias, B. G., Ahrens, R. N. M., Allen, M. S., Tuten, T., Siders, Z. A., & Wilson, K. L. (2018). Understanding the effects of density and environmental variability on the process of fish growth. *Fisheries Research*, 198, 209–219. <https://doi.org/10.1016/j.fishres.2017.08.018>
- McAlpine, D. F., Connell, C. B., & Seymour, P. D. (2020). Introduction of Southern White River Crayfish (*Procambarus zonangulus*) to New Brunswick. *The Canadian Field-Naturalist*, 134(4), 375–378. <https://doi.org/10.22621/cfn.v134i4.2575>
- McInerney, M. C., & Cross, T. K. (1999). Effects of lake productivity, climate warming, and intraspecific density on growth and growth patterns of Black Crappie in Southern Minnesota lakes. *Journal of Freshwater Ecology*, 14(2), 255–264. <https://doi.org/10.1080/02705060.1999.9663677>
- McPhail, D. (2021). The B.C. distribution of black crappie, *Pomoxis nigromaculatus*. In B. Klinkenberg (Ed.) *E-Fauna BC: Electronic Atlas of the Fauna of British Columbia [efauna.bc.ca]*. [Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver]. Accessed: 2022-03-12 8:48:49 AM <https://linnet.geog.ubc.ca/efauna/Images/Maps/Fish/largemaps/Pomoxis%20nigromaculatus.png>
- McPhail, J. D., & McPhail, D. L. (2007). *The freshwater fishes of British Columbia*. University of Alberta Press.
- Merriam-Webster. (2022). *Crappie Definition & Meaning*. Merriam-Webster. <https://www.merriam-webster.com/dictionary/crappie>
- Miller, J. W., Kocovsky, P. M., Wiegmann, D., & Miner, J. G. (2018). Fish community responses to submerged aquatic vegetation in Maumee Bay, western Lake Erie. *North American Journal of Fisheries Management*, 38(3), 623–629. <https://doi.org/10.1002/nafm.10061>
- Ming, A. (1971). *A review of the literature on crappies in small impoundments*. (Study No. 7-15, Job No. 1; Federal Aid in Fish Restoration, Project F-1-R-20, p. 53 pp.). Missouri Department of Conservation. <https://myfwf.mt.gov/getRepositoryFile?objectID=51018>
- Mitiku, M. A. (2018). A review on Columnaris disease in freshwater farmed fish. *International Journal of Advanced Research in Biological Sciences*, 5(6), 79–90. <http://dx.doi.org/10.22192/ijarbs.2018.05.06.007>

- Mitzner, L. (1991). Effect of environmental variables upon crappie young, year-class strength, and the sport fishery. *North American Journal of Fisheries Management*, 11(4), 534–542.
[https://doi.org/10.1577/1548-8675\(1991\)011<0534:EOEVUC>2.3.CO;2](https://doi.org/10.1577/1548-8675(1991)011<0534:EOEVUC>2.3.CO;2)
- Morris, J. E., & Clayton, R. D. (2009). Centrarchid Aquaculture. In S. J. Cooke & D. P. Philipp (Eds.), *Centrarchid Fishes* (pp. 293–311). Wiley-Blackwell.
<https://onlinelibrary.wiley.com/doi/10.1002/9781444316032.ch10>
- Nagid, E. J., Dockendorf, K. J., & Hujik, R. W. (2004). Off-season spawning of Black Crappie in a north-central Florida Lake. *North American Journal of Fisheries Management*, 24(1), 299–302.
<https://doi.org/10.1577/M02-165>
- NatureServe. (2022a). *NatureServe Explorer [web application]* [NatureServe, Arlington, Virginia.].
<https://explorer.natureserve.org/>
- NatureServe. (2022b, January 10). *Pomoxis nigromaculatus* | *NatureServe Explorer*. NatureServe Explorer [Web Application].
https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.103134/Pomoxis_nigromaculatus
- Near, T. J., Sandel, M., Kuhn, K. L., Unmack, P. J., Wainwright, P. C., & Leo Smith, Wm. (2012). Nuclear gene-inferred phylogenies resolve the relationships of the enigmatic Pygmy Sunfishes, *Elassoma* (Teleostei: Percomorpha). *Molecular Phylogenetics and Evolution*, 63(2), 388–395.
<https://doi.org/10.1016/j.ympev.2012.01.011>
- Neumann, R. M., & Murphy, B. R. (1991). Evaluation of the relative weight (Wr) index for assessment of White Crappie and Black Crappie populations. *North American Journal of Fisheries Management*, 11(4), 543–555. [https://doi.org/10.1577/1548-8675\(1991\)011<0543:EOTRWW>2.3.CO;2](https://doi.org/10.1577/1548-8675(1991)011<0543:EOTRWW>2.3.CO;2)
- Page, L. M., & Burr, B. M. (2011). *Peterson field guide to freshwater fishes of North America north of Mexico* (2nd ed). Houghton Mifflin Harcourt.
- Pangle, K. L., Malinich, T. D., Bunnell, D. B., DeVries, D. R., & Ludsins, S. A. (2012). Context-dependent planktivory: Interacting effects of turbidity and predation risk on adaptive foraging. *Ecosphere*, 3(12), art114. <https://doi.org/10.1890/ES12-00224.1>
- Parsons, B. G., & Reed, J. R. (2005). Movement of Black Crappies and Bluegills among interconnected lakes in Minnesota. *North American Journal of Fisheries Management*, 25(2), 689–695.
<https://doi.org/10.1577/M04-021.1>
- Parsons, G. (2015). *Promoting crappie recruitment in northwest Mississippi reservoirs: Adult movement and spawning habitat*. (p. 60). Prepared for: The Mississippi Department of Wildlife Fisheries and Parks.
- Pelham, M. E., Pierce, C. L., & Larscheid, J. G. (2001). Diet dynamics of the juvenile piscivorous fish community in Spirit Lake, Iowa, USA, 1997-1998. *Ecology of Freshwater Fish*, 10(4), 198–211.
<https://doi.org/10.1034/j.1600-0633.2001.100402.x>
- Phelps, Q. E., Lohmeyer, A. M., Wahl, N. C., Zeigler, J. M., & Whitley, G. W. (2009). Habitat characteristics of Black Crappie nest sites in an Illinois impoundment. *North American Journal of Fisheries Management*, 29(1), 189–195. <https://doi.org/10.1577/M07-110>
- Pine III, W. E., & Allen, M. S. (2001). Differential growth and survival of weekly age-0 Black Crappie cohorts in a Florida lake. *Transactions of the American Fisheries Society*, 130, 80–91.
[https://doi.org/10.1577/1548-8659\(2001\)130<0080:DGASOW>2.0.CO;2](https://doi.org/10.1577/1548-8659(2001)130<0080:DGASOW>2.0.CO;2)
- Plourde, M.-A. (2021). *Draft: June 1-3 2021 site visit Big Lake located near Millville NB*. Fisheries and Oceans Canada.
- Pope, K. L., Geraets, W. T., & Willis, D. W. (1996a). Egg development in a high-density Black Crappie (*Pomoxis nigromaculatus*) population. *Journal of Freshwater Ecology*, 11(4), 451–458.
<https://doi.org/10.1080/02705060.1996.9664473>

- Pope, K. L., & Willis, D. W. (1997). Environmental characteristics of black crappie (*Pomoxis nigromaculatus*) nesting sites in two South Dakota waters. *Ecology of Freshwater Fish*, 6(4), 183–189. <https://doi.org/10.1111/j.1600-0633.1997.tb00161.x>
- Pope, K. L., & Willis, D. W. (1998). Early life history and recruitment of black crappie (*Pomoxis nigromaculatus*) in two South Dakota waters. *Ecology of Freshwater Fish*, 7(2), 56–68. <https://doi.org/10.1111/j.1600-0633.1998.tb00172.x>
- Pope, K. L., Willis, D. W., & Lucchesi, D. O. (1996b). Differential relations of age-0 Black Crappie and Yellow Perch to climatological variables in a natural lake. *Journal of Freshwater Ecology*, 11(3), 345–350. <https://doi.org/10.1080/02705060.1996.9664457>
- Porreca, A. P., Rude, N. P., Broadway, K. J., Wahl, D. H., & Parkos, J. J. (2020). Differential performance of sympatric *Pomoxis* species is explained by habitat-linked morphology. *Transactions of the American Fisheries Society*, 149(5), 565–575. <https://doi.org/10.1002/tafs.10257>
- Post, J. R., Rudstam, L. G., & Schael, D. M. (1995). Temporal and spatial distribution of pelagic age-0 fish in Lake Mendota, Wisconsin. *Transactions of the American Fisheries Society*, 124(1), 84–93. [https://doi.org/10.1577/1548-8659\(1995\)124<0084:TASDOP>2.3.CO;2](https://doi.org/10.1577/1548-8659(1995)124<0084:TASDOP>2.3.CO;2)
- Quinn, S., & Paukert, C. (2009). Centrarchid Fisheries. In S. J. Cooke & D. P. Philipp (Eds.), *Centrarchid Fishes* (pp. 312–339). Wiley-Blackwell. <https://onlinelibrary.wiley.com/doi/10.1002/9781444316032.ch11>
- Rawson, D. S., & Ruttan, R. A. (1952). Pond fish studies in Saskatchewan. *The Journal of Wildlife Management*, 16(3), 283. <https://doi.org/10.2307/3796640>
- Reed, J. R., & Pereira, D. L. (2009). Relationships between shoreline development and nest site selection by Black Crappie and Largemouth Bass. *North American Journal of Fisheries Management*, 29(4), 943–948. <https://doi.org/10.1577/M06-234.1>
- Riso, C. (2011). *Pomoxis nigromaculatus* – Black Crappie. Fish 423. Washington Department of Fish and Wildlife. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjCqbn2oJv1AhVQOs0KHRIpCX0QFnoECAYQAQ&url=https%3A%2F%2Fdepts.washington.edu%2Foldenlab%2Fwordpress%2Fwp-content%2Fuploads%2F2013%2F03%2FPomoxis-nigromaculatus_Riso.pdf&usq=AOvVaw1g5wY4hD1s9FOEtrg7iVse
- Ross, J. R., Crosby, J. D., & Kosa, J. T. (2005). Accuracy and precision of age estimation of crappies. *North American Journal of Fisheries Management*, 25(2), 423–428. <https://doi.org/10.1577/M04-083.1>
- Ruiz-Campos, G. (2021). *Actualización de la base de datos computarizada de la colección ictiológica de la Universidad Autónoma de Baja California. Version 1.10. Occurrence dataset*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO); Accessed via GBIF.org on 2022-01-21. <https://www.gbif.org/occurrence/1422096775>. <https://doi.org/10.15468/mrii16>
- Ruiz-Campos, G., Varela-Romero, A., Sánchez-Gonzales, S., Camarena-Rosales, F., Maeda-Martínez, A. M., González-Acosta, A. F., Andreu-Soler, A., Campos-González, E., & Delgadillo-Rodríguez, J. (2014). Peces invasores en el noroeste de México. In R. Mendoza & P. Koleff (Eds.), *Especies acuáticas invasoras en México*. (pp. 375–399). Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). http://www1.inecol.edu.mx/cv/CV_pdf/miguel_rubio/Acuaticas_invasoras.pdf
- Saskatchewan Conservation Data Centre (SCDC). (2021). *Saskatchewan Vertebrate Taxa List* (p. 48 pp.). Saskatchewan Conservation Data Centre. www.biodiversity.sk.ca/SppList.htm
- Schael, D. M., Rudstam, L. G., & Post, J. R. (1991). Gape limitation and prey selection in larval Yellow Perch (*Perca flavescens*), Freshwater Drum (*Aplodinotus grunniens*), and Black Crappie (*Pomoxis nigromaculatus*). *Canadian Journal of Fisheries and Aquatic Sciences*, 48(10), 1919–1925. <https://doi.org/10.1139/f91-228>

- Scott, W. B., & Crossman, E. J. (1973). *Freshwater Fishes of Canada* (1979th ed.). Fisheries Research Board of Canada.
- Sheehan, R., Lewis, W. M., & Bodensteiner, L. (1994). *Winter habitat requirements and overwintering of riverine fishes* (Final Performance Report Paper 8; Reports, p. 156). Fisheries Research Laboratory, Southern Illinois University. http://opensiuc.lib.siu.edu/fiaq_reports/8
- Sikora, L. W., VanDeHey, J. A., Sass, G. G., Matzke, G., & Preul, M. (2021). Fish community changes associated with bullhead removals in four northern Wisconsin lakes. *North American Journal of Fisheries Management*, 41(S1). <https://doi.org/10.1002/nafm.10594>
- Smithsonian Tropical Research Institute (STRI). (2022). *STRI Research Portal Collection, Specimen Records, Occurrence Records: Pomoxis*. Smithsonian Tropical Research Institute. <https://panamabiota.org/stri/collections/list.php?usethes=1&taxa=5848#>
- spaghetti. (2012, March 31). *Does Alberta have any Panfish?* [Online forum post]. Alberta Outdoorsman Forum. <http://www.outdoorsmenforum.ca/showthread.php?t=127719>
- Spier, T. W., & Heidinger, R. C. (2002). Effect of turbidity on growth of Black Crappie and White Crappie. *North American Journal of Fisheries Management*, 22, 1438–1441. [https://doi.org/10.1577/1548-8675\(2002\)022<1438:EOTOGO>2.0.CO;2](https://doi.org/10.1577/1548-8675(2002)022<1438:EOTOGO>2.0.CO;2)
- Stantec. (2016). *Mactaquac Project: Final comparative environmental review (CER) report*. (p. 80 pp.). Prepared for: New Brunswick Power Corporation. <https://www.nbpower.com/en/about-us/news-media-centre/news/2016/mactaquac-project-update-environmental-social-scientific-and-public-engagement-reports-now-available/>
- Stepien, C. A., Pierce, L. R., Leaman, D. W., Niner, M. D., & Shepherd, B. S. (2015). Gene diversification of an emerging pathogen: A decade of mutation in a novel fish Viral Hemorrhagic Septicemia (VHS) substrain since its first appearance in the Laurentian Great Lakes. *PLOS ONE*, 10(8), e0135146. <https://doi.org/10.1371/journal.pone.0135146>
- Suski, C. D., & Ridgway, M. S. (2009). Winter biology of Centrarchid fishes. In S. J. Cooke & D. P. Philipp (Eds.), *Centrarchid Fishes* (pp. 264–292). Wiley-Blackwell. <https://onlinelibrary.wiley.com/doi/10.1002/9781444316032.ch9>
- Swing, J. M., & McGowan, E. G. (1987). Characteristics for distinguishing flier (*Centrarchus macropterus*) and Black Crappie (*Pomoxis nigromaculatus*) larvae. *Journal of the Elisha Mitchell Scientific Society*, 103(3), 81–87. <https://www.jstor.org/stable/24333490>
- Telesnicki, G. J., & Goldberg, W. M. (1995). Comparison of turbidity measurement by nephelometry and transmissometry and its relevance to water quality standards. *Bulletin of Marine Science*, 57(2), 540–547. <https://www.ingentaconnect.com/content/umrsmas/bullmar/1995/00000057/00000002/art00017>
- United States Department of Agriculture (USDA). (2019). *2018 Census of Aquaculture*. (Volume 3, Special Studies, Part 2 AC-17-SS-2; 2017 Census of Agriculture). https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Aquaculture/index.php
- U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau (USFWS). (2016). *2016 national survey of fishing, hunting, and wildlife-associated recreation*. (p. 132). USFWS. <https://www.census.gov/library/publications/2018/demo/fhw-16-nat.html>
- United States Geological Survey (USGS). (2022, February 4). *Nonindigenous aquatic species—Pomoxis nigromaculatus*. USGS. <https://nas.er.usgs.gov/viewer/omap.aspx?SpeciesID=409>
- Universidad del Valle de Guatemala (UVG). (2021). *Universidad del Valle de Guatemala—Colecciones Biológicas—Peces. Occurrence dataset*. Accessed; Accessed via GBIF.org on 2022-01-21. <https://www.gbif.org/occurrence/2864014282>. <https://doi.org/10.15468/8hbbse>

- Varela Romero, A. (2021). *Colección de los peces nativos de Sonora. Occurrence dataset*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO); Accessed via GBIF.org on 2022-01-21. <https://www.gbif.org/occurrence/1418069615>. <https://doi.org/10.15468/kpxpgx>
- Wallus, R., Simon, T.P. (2008) Vol. 6 : Elasmobranchidae and Centrarchidae. In R. Wallus & T.P. Simon (Eds), *Reproductive Biology and Early Life History of Fish in the Ohio River Drainage*. CRC Press Inc. Boca Raton, USA.
- Wang, J. C. S., & Kernehan, R. J. (1979). *Fishes of the Delaware estuaries: A guide to the early life histories*. EA Communications, Ecological Analysts, Inc.
- Warren, M. L. (2009). Centrarchid identification and natural history. In S. J. Cooke & D. P. Philipp (Eds.), *Centrarchid Fishes* (pp. 375–533). Wiley-Blackwell. <https://onlinelibrary.wiley.com/doi/10.1002/9781444316032.ch13>
- Weber, M. J., & Brown, M. L. (2012). Diel and temporal habitat use of four juvenile fishes in a complex glacial lake. *Lake and Reservoir Management*, 28(2), 120–129. <https://doi.org/10.1080/07438141.2012.675414>
- Wegscheider, B., Linnansaari, T., Wall, C. C., Gautreau, M. D., Monk, W. A., Dolson-Edge, R., Samways, K. M., & Curry, R. A. (2020). Diel patterns in spatial distribution of fish assemblages in lentic and lotic habitat in a regulated river. *River Research and Applications*, 36(7), 1014–1023. <https://doi.org/10.1002/rra.3615>
- Welcome, R. L. (1988). *International introductions of inland aquatic species*. (No. 294; FAO Fisheries Technical Paper, p. 318 p.). Food and Agriculture Organization of the United Nations (FAO). <https://www.fao.org/3/X5628E/x5628e0d.htm#pomoxis%20nigromaculatus%20lesueur:%20centrarchidae>
- Whitledge, G. W., Johnson, B. M., Martinez, P. J., & Martinez, A. M. (2007). Sources of nonnative Centrarchids in the Upper Colorado River revealed by stable isotope and microchemical analyses of otoliths. *Transactions of the American Fisheries Society*, 136(5), 1263–1275. <https://doi.org/10.1577/T06-045.1>