The Essential Bait Field Guide

for Eastern Canada, the Great Lakes Region and Northeastern United States

Featuring baitfish, minnows, small fishes, crayfishes, frogs and leeches

Edited by Guy Winterton

Written and illustrated by leading experts in the bait industry

Crayfishes

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An Illustrated Guide to the Crayfishes of Ontario

INTRODUCTION

Having arisen from marine ancestors approximately 400 million years ago, a group of crustaceans commonly referred to as crayfishes have had a long and successful evolutionary history (*Schram, 1982; Wheatly and Gannon, 1995*). Crayfish is the term most often used to describe this unique group of animals but to many these primitive looking creatures are also known as crawfishes, crawdads or mudbugs (*Brown and Gunderson, 1997; Hobbs Jr., 1988*).

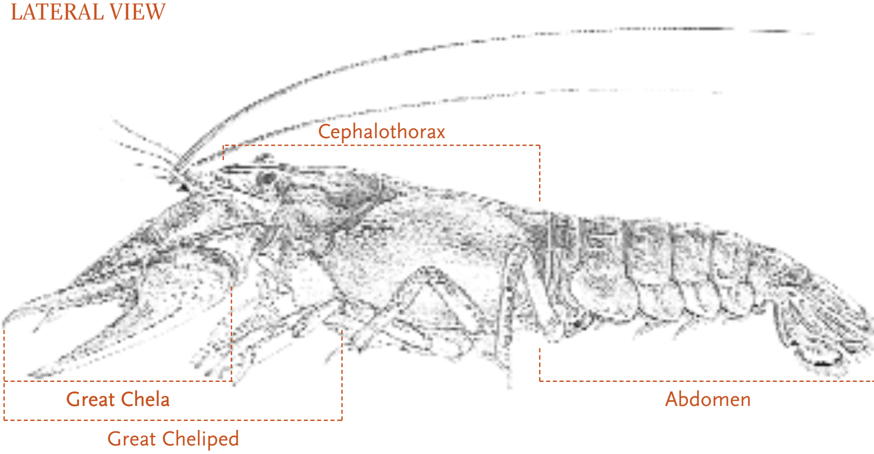
Crayfishes are found almost everywhere and are native inhabitants of every continent except Africa (where they have been introduced) and Antarctica (*Taylor et al., 1996*). Crayfishes are also the largest mobile animals without backbones (invertebrates) in both semi-terrestrial (e.g. burrowing crayfishes) and surface water ecosystems (*Holdich and Lowery, 1988*). Due to their large size and abundance, crayfishes continue to be the focus of zoological classroom teachings and research programs alike (*Lowery, 1988*).

In habitats occupied by crayfishes, their presence represents an integral component within food webs. Feeding habit studies indicate that crayfishes are remarkably flexible in relation to their dietary requirements. Crayfishes are polytrophic animals, meaning they are at the same time herbivores, omnivores, detrivores and carnivores. As a result, crayfishes are referred to by some as "ecological rubbish collectors" (*Hogger, 1988*). By utilizing detritus, aquatic vegetation and animal matter in their diets, crayfishes act as conduits, transferring energy from lower trophic levels directly to higher trophic level crayfish predators (*Huryn and Wallace, 1987; Griffith et al., 1994; Taylor et al., 1996*). This is not surprising considering that crayfishes comprise a significant proportion of the biomass within many ecosystems (*Rabeni, 1992; Griffith et al., 1994; Taylor et al., 1996*). Consequently, crayfishes also help to sustain recreational and commercial fisheries and in some areas serve as a popular and important human food resource (*Taylor et al., 1996*).

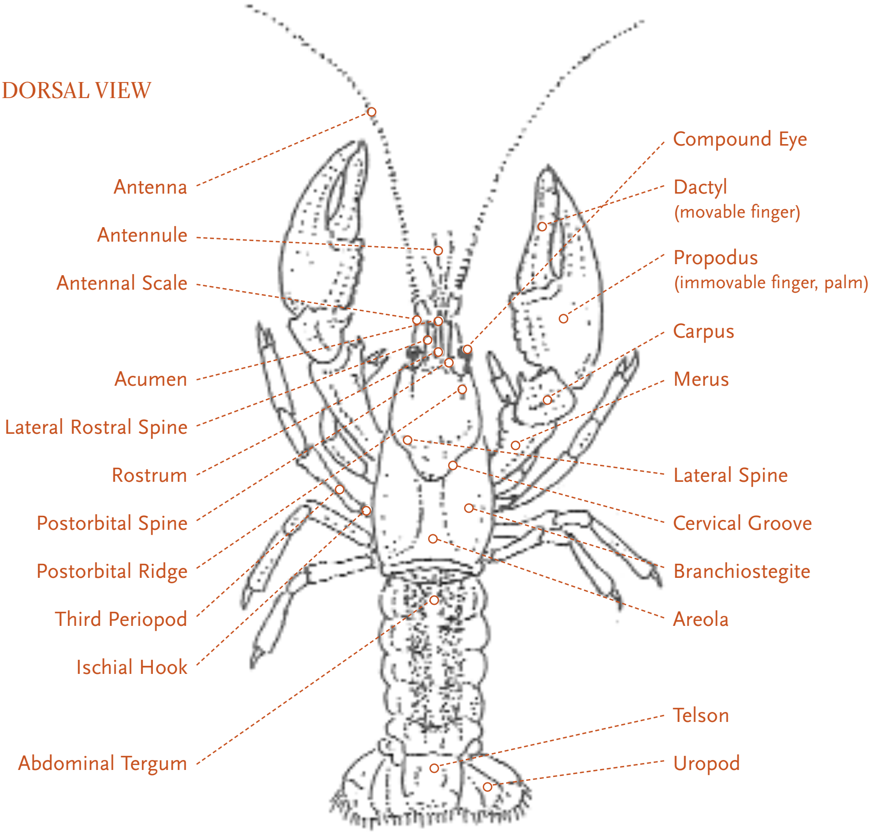
In many regions of Ontario crayfishes are also harvested or cultured and sold as fishing bait. In the province of Ontario alone, the baitfish industry is estimated to generate between $40-60 million annually. Over the last few years, interest in the biology and ecological diversity of the crayfishes in North America has expanded as a result of the dedicated work of numerous individuals. Consequently, there exists today an expanding body of scientific literature devoted entirely to the study of these unique and fascinating animals.

ANATOMICAL GUIDE AND GLOSSARY

LATERAL VIEW



DORSAL VIEW



GLOSSARY OF SELECTED TERMS

Acumen: terminal spine (tip) of rostrum

Antenna: long whip-like, paired sensory appendage

Allopatric: not occurring in the same habitat

Areola: mid-dorsal area on carapace, usually hour-glass shaped

Anterior: toward the front

Antennules: small paired head appendages used for sensory reception

Annulus ventralis: female copulatory apparatus; external sperm storage organ on underside of thorax; seminal receptacle, refers to females

Basal: part closest to the body

Berried (in berry): with eggs attached to swimmerets; brooding, ovigerous, refers to females

Carina: raised ridge on middle of rostrum

Caudal: posterior, toward the back of

Cheliped or chelae: first walking leg modified into a pincer, claw

Carapace: fused head and thorax of decapod Crustacea; cephalothorax

Carapace length (CPL): standard size measurement of crayfish; tip of rostrum to middle of dorsal edge of carapace

Cephalothorax: see carapace

Cephalic: dealing with the head

Cervical groove: groove of fissure separating head (cephalic) portion from thorax portion of cephalothorax

Crustacea: class of animal with hard crust or shell, segmented body, chitinous exoskeleton, and paired, jointed legs

Cyclic dimorphism: alternation between Form I and form II in male crayfishes in the family Cambaridae

Dactyl: movable finger of chelae

Decapod: marine or freshwater crustacean with hard exoskeleton and jointed appendages

Distal: of, toward, in, on, or near the back

Endemic: occurring in a specific region (or country) only

Exoskeleton: external skeleton or shell of crayfishes which is shed during moulting

Form I: sexually active male phase with sharp, calcified stylets and large chelae, good indicator of male maturity

Form II: sexually inactive male phase with dull decalcified stylets, and smaller chelae

Gonopods: see stylets

Glair: substance which helps in the attachment of eggs to female's swimmerets; extruded during oviposition from conspicuous glands in abdomen and tail fan, good indicator of female maturity

Hepatopancreas: digestive gland

Ischial hooks: hooks found of upper part of walking leg (ischium) in Form I males of the Family Cambaridae (Orconectes, Cambarus and Fallicambarus in Canada)

Intermoult: period between moults when exoskeleton is hard

Lateral: on the side

Lateral Rostral Spines: Lateral (or marginal) spines at base of acumen on rostrum

Maxillipeds: one of three pairs of crustacean head appendages located just behind maxillae

Medial: of the middle; also mesial

Merus: fourth segment of periopod, meral: dealing with merus

Moult/moulting: the shedding of the exoskeleton; process of growth in Crustacea

Ovigerous: see berried (in berry)

Palm: broad portion of claw

Pleopod: abdominal appendage; swimmeret; found on underside of abdomen, see also stylets

Pereiopod: walking leg, thoracic appendage, can include chela.

Postorbital: behind the orbit of the eye

Proximal: close to, next to

Range: area of general occurrence for a species

Rostrum: projection of carapace between the eyes, usually terminated by a point (acumen); rostral: dealing with the rostrum

Seminal receptacle: see annulis ventralis

Setae: hair like structures on the exoskeleton of crayfishes

Stage 1, 2 & 3: the sequential "larval" stages of young crayfish while attached to their mothers

Stylets: male copulatory apparatus; modified first and/or second pairs of pleopods

Sympatric: occurring in the same habitat

Telson: central appendage of tail fan

Terminal: at the end, last

Thorax: portion of carapace between cephalic groove and abdomen

Tubercles: low rounded bumps of chelae or carapace

Uropods: lateral appendages (4) of tail fan

Ventral: abdominal, the belly side, underside

APPALACHIAN BROOK CRAYFISH

Cambarus bartonii bartonii

Found in streams, rivers and lakes. The Appalachian Brook Crayfish is most common in fast flowing, rocky areas which remain cool and well oxygenated in the summer. It is therefore often associated with rapids and waterfalls.

DESCRIPTION: The Appalachian Brook Crayfish is also known as Ecrevisse du Nord. It is a medium to small crayfish with generally smooth appearance, small eyes set into the carapace and smooth chela with fingers curved inwards. It is distinguished from the similar species the Robust Crayfish by a shorter rostrum and single row of tubercules on inner border of palm of chelipeds. Colouring is characteristically orange-brown but can also be blueish-green. Blue morphs of this species have been recorded in Ontario *(Crocker and Barr, 1968; Hamr, unpublished data)*.

DISTRIBUTION: Canada/Ontario – This species is found in New Brunswick, Quebec and Ontario. In Ontario, where its distribution has been well documented, it is found from the Moose River drainage in the north, westward to the eastern shore of Lake Superior, south to the western end of Lake Ontario and east to the Ottawa-St. Lawrence River drainages *(Crocker and Barr, 1968; Berrill 1978; Hamr 1983; David et al., 1994, Guiasu et al., 1996; David et al., 1997;)*. In Quebec its distribution remains largely undocumented but it occurs in both the St. Lawrence River and Ottawa River drainages. To date it has been collected from the Ottawa region south to Montreal and eastward, on both north and south shores of the St. Lawrence River to the Madawaska drainage on the New Brunswick border *(Bousfield, 1969; Burgess and Bider, 1980; Schueler, 1985; Dube (unpublished records); Hamr (unpublished records)*. The species is also found in the Laurentides region north of the St. Lawrence River *(Dube, unpublished records)* and it is very likely to range as far north as James Bay. In New Brunswick, the Appalachian Brook Crayfish is found in the Saint John, the Restigouche and in the Miramichi drainages. No crayfishes have been observed in any of the Northumberland Strait or in east Bay of Fundy rivers *(Schueler, 1985; Hooper pers. comm.)*.

North America – This species is widely distributed along the eastern part of North America and has been recorded from New Brunswick, Quebec, Ontario, Maine, Massachusetts, Rhode Island, Vermont, New York, New Jersey, Connecticut, Pennsylvania, Maryland, District of Columbia, Delaware, Virginia, West Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia and Alabama.

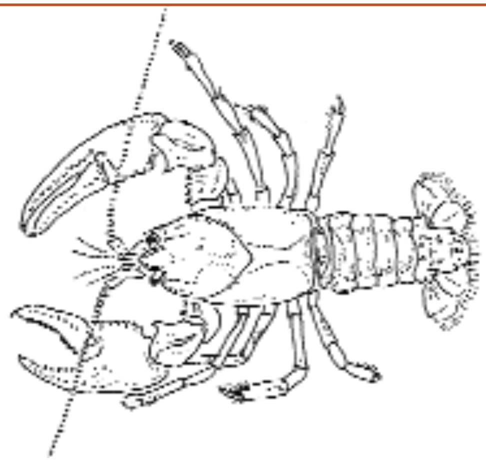


FIGURE 1: *Black and white drawing of the Appalachian Brook Crayfish (Cambarus bartonii bartonii) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

HABITAT AND ECOLOGY: This species is most common in fast flowing, rocky areas which remain cool and well oxygenated in the summer *(Crocker and Barr, 1968; Bousfield, 1969; Berrill, 1978; Hamr and Berrill, 1985; Guiasu et al., 1996)*. Shelters usually consist of excavations in gravel and sand under larger rocks *(Crocker and Barr, 1968; Hamr, 1983)*. The species shows a remarkable ability to penetrate deep into the substrate. Excavations can go as deep as 1 m throughout several layers of rock and gravel *(Hamr, 1983)*. On the Canadian Shield in Ontario, this species has been found in deep, high elevation lakes spanning abroad range of pH values (5.0->7.0) *(David et al., 1994)*.

In Canada, this species has been found together with Robust Crayfish, Northern Clearwater Crayfish, Virile Crayfish, Obscure Crayfish, Papershell Crayfish and Rusty Crayfish *(Berrill, 1978; Hamr, 1983; David et al., 1997)*. In laboratory studies the Appalachian Brook Crayfish was found to be clearly more aggressive than Virile Crayfish and Northern Clearwater Crayfish but less aggressive than Robust Crayfish *(Guiasu and Dunham, 1997)*.

LIFE HISTORY: In Ontario, reproduction appears to take place from spring to fall. Mature females show strong glair gland development from April to August. Copulation has been observed in October in the wild and late April to early June in captivity. Females with eggs are found from June to August and with young from July to September. Eggs and young are therefore carried into autumn and there is evidence that some females may over winter with attached eggs or young and release them (and then moult) the following summer *(MacManus, 1960b; Hamr, 1983)*. Hatching occurs between July and August and the young undergo two moults in their metamorphosis, spending about 15 days attached to their mothers. Free-living young measuring about 5 mm (0.195 in.) CPL are first found in August *(Hamr, and Berrill, 1985)*.

Moulting in immature crayfishes take place form May to early October and maturity is reached at about 2 years of age. Adult males moult in July and September. Moulting into both Form I and Form II at the same time of year has been observed *(Hamr and Berrill, 1985)*. Mature females moult once following the reproductive season but the timing of moult is variable (September or the following June-July) depending on local conditions. The average life-span appears to be 3 years old and the maximum life-span is 4 years. The maximum recorded size is 39 mm (1.52 in.) CPL from a male collected in Rawdon, Quebec. Sexual dimorphism with respect to chela length between sexes and Form I and From II males is present but not as pronounced as in the Orconectid crayfishes *(Hamr and Berrill, 1985)*.

CONSERVATION STATUS: Although this species remains fairly common in certain parts of Ontario, many recent collections come primarily from within protected areas inside provincial parks and conservation areas where riparian vegetation surrounding streams is well preserved and the level of water pollution and human interference is generally lower than elsewhere *(Barr, 1996)*. Similarly, populations of this species have been found in waters infested with the introduced Rusty Crayfish (e.g. Otonabee River, Ontario). A major environmental pressure is the gradual acidification of lakes and streams due to acid rain, particularly in southeastern Ontario *(DiStefano et al., 1991)*. Although mature Appalachian Brook Crayfish appear to be somewhat acid tolerant, it has been demonstrated that juvenile and moulting crayfishes may be more vulnerable to the acidification process than larger, intermoult individuals *(Berrill et al., 1985; DiStefano et al., 1991)*. A study of crayfishes in lakes of the Canadian (Precambrian) Shield in Ontario found significant decreases in the Appalachian Brook Crayfish populations. It was suggested that these declines may be linked to low pH and high aluminum concentrations *(David et al., 1997)*. Studies of this species in the Sudbury area where emissions of heavy metals remain high, showed that although metals were accumulated the species appeared to tolerant of copper, cadmium and nickel *(Bagatto and Alikhan, 1987; Zia and Alikhan, 1989)*.

The closely related Robust Crayfish has been shown to be clearly dominant in aggressive interactions with the Appalachian Brook Crayfish and the distribution of the two is largely non-overlapping. Given the apparent range expansion of Robust Crayfish in Ontario and Quebec during the past 30 years it appears that this species has the potential to competitively exclude the Appalachian Brook Crayfish if the two species are competing for limited resources *(Guiasu and Dunham, 1997)*. In conclusion, this species has a fairly extensive distribution with apparently many "safe" northern populations and should therefore be considered to have a "Currently Stable" status in Canada *(Hamr, 1998)*.

CHIMNEY/DIGGER CRAYFISH

CHIMNEY/DIGGER CRAYFISH

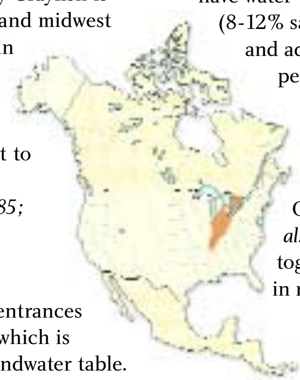
Fallicambarus fodiens

A semi-terrestrial burrower. The Chimney Crayfish spends most of its life within burrows consisting of a network of tunnels.

DESCRIPTION: This species has no official common names, but is sometimes referred to as Chimney or Digger crayfish. It is a medium-sized, obligate burrowing, semi-terrestrial crayfish, distinguished from similar species (Devil Crawfish) by presence of notch on movable finger of chela. Colouring is uniform light brown to rust or red-olive brown with darker mottling.

DISTRIBUTION: Canada/Ontario – This species is the only representative of its genus occurring in Canada where it is at the extreme northern edge of its range. It is restricted to southern Ontario where it occurs from south of Lake Simcoe and west of Lake Scugog to Lake St. Clair and the Detroit River *(Crocker and Barr, 1968; Hamr unpublished data; Guiasu et al., 1996; Barr, 1996)*.

North America – The Chimney Crayfish is widely distributed in the east and midwest of North America. It is found in Ontario, Michigan, Ohio, Illinois, Indiana, West Virginia, Maryland, Alabama, Georgia, Florida as well as west to Missouri, Arkansas, Louisiana, Oklahoma and Texas *(Page, 1985; Hobbs Jr. and Robinson, 1989)*.



HABITAT AND ECOLOGY: The burrows have as many as four entrances and a large terminal chamber which is usually located below the groundwater table. The entrances are usually made conspicuous by tall "chimneys" constructed from pellets of excavated mud. Chimney Crayfish burrows are found in wetlands (marshes and swamps) but also along roadside ditches and creek banks in moist clay, among rooted semi aquatic plants and grasses. Burrowing activity appears to be the greatest in the spring and following periods of heavy rainfall, in order to repair damaged burrows *(Williams, 1974)*. Excavation is also increased as the water table drops and crayfish burrow to greater depths to reach ground water.

This species needs primarily clay soils in order to burrow *(Crocker and Barr, 1968)* and thus the hard rocks and thin soils of the Canadian Shield may limit the availability of suitable habitats and northward range expansion. The burrows of this species may have water with low oxygen concentrations (8-12% saturation) *(Williams et. al., 1974)* and adults can survive for prolonged periods (up to several weeks) out of water if the humidity of the air is high enough. The Chimney Crayfish has never been found together with Devil Crawfish in Canada *(Guiasu et al., 1996)* but it does occur together with Papershell Crayfish in roadside ditches and wetlands in southwestern Ontario *(Hamr, unpublished data)*.

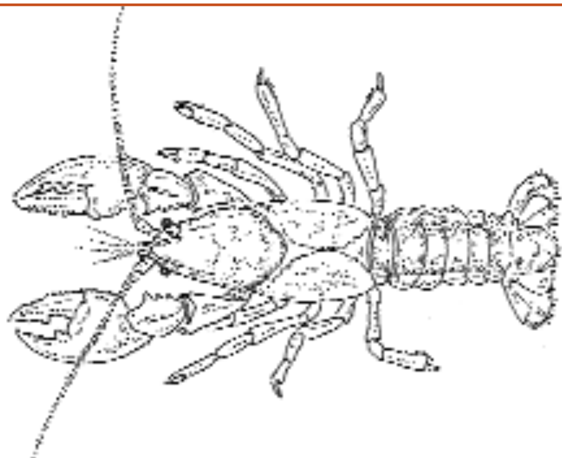


FIGURE 2: *Black and white drawing of the Chimney Crayfish (Fallicambarus fodiens) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

LIFE HISTORY: Little is known of the life history of the Canadian populations of Chimney Crayfishes. The only published study available *(Williams et al., 1974)*, in a temporary stream bed near Waterloo, Ontario, reported that crayfishes became active in early April and eggs were laid by the end of the month. In early May, free-living juveniles measuring 6 mm CPL were found in open water. It was estimated therefore that in this population, crayfishes reached sexual maturity after two summers (at a CPL of about 30 mm/1.2 in.). Maximum size was 35 mm (1.36 in.) CPL. No mating occurred in the fall and little activity was observed from late October to early April.

Berrill (unpublished data) found that populations in the Holland Marsh, Ontario sampled from May included Form I males, females with cement glands of various stages of development, immature individuals of both sexes (and young of the year). The maximum size reported was 36 mm (1.4 in.) CPL. It appears therefore that this species in Ontario may breed from May to June, attain maturity at CPL of 25-30 mm (0.98-1.17 in.) and survive to 3-4 years maximum. As you go north through the species' range, populations tend to breed later in the spring or summer and have a larger size at maturity *(Hobbs Jr. and Robinson, 1989; Page, 1985)*. However, more detailed life history studies are needed to clarify the life history of the northern populations.

CONSERVATION STATUS: Populations of Chimney Crayfishes are scattered over a wide geographic area but are never locally common and are restricted to isolated patches of wetland habitat, usually in the midst of extensive agricultural and urban areas. The amount of available habitat suitable for Chimney Crayfishes is decreasing. The species range coincides with heavily urbanized and industrialized areas *(Barr, 1996)* as well as the center of most of Ontario's agricultural production. *Guiasu et al., (1996)*, found that several of the Toronto locations reported by *Crocker and Barr (1968)*, which had Chimney Crayfish colonies in the early and mid-1960s, have since been developed for industrial or commercial purposes.

Similarly, areas within the jurisdiction of the Metropolitan Toronto and Toronto Region Conservation Authority, which also used to support Chimney Crayfish populations, have now become unsuitable for these crayfish, due to urban development *(Guiasu et al. 1996)*. Therefore, there is sufficient evidence to suggest that Chimney Crayfish is "Vulnerable' in Ontario, as the probability of habitat destruction and thus local extinctions is high throughout the vast majority of its range *(Hamr, 1998)*.

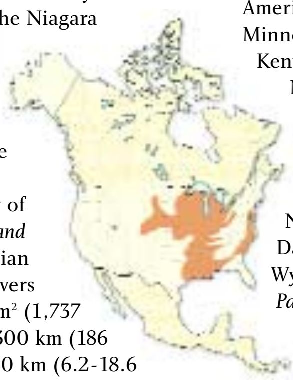
DEVIL CRAWFISH

Cambarus diogenes

Burrows in coastal wetlands, mudflats, wet meadows and marshes. It is wide-ranging in North America which reflects a wide tolerance to varying ecological conditions.

DESCRIPTION: The Devil Crawfish is also referred to as the Meadow crayfish. It is a large, burrowing, semi-terrestrial crayfish, distinguished from similar species (Chimney Crayfish) by lack of notch on movable finger of chela and lateral continuation of the cervical groove. Colouring is dark reddish-brown to olive green with orange-red margins of chelipeds.

DISTRIBUTION: Canada/Ontario – The Devil Crawfish is found only in southwestern Ontario where it is at the very extreme edge of its northernmost range. The Canadian range was recently extended westward to the Niagara Peninsula by *Guiasu et al., (1996)*. *Hamr (unpublished)* has found new sites on the northern portion of the Long Point Peninsula suggesting the viability of those cited by *Crocker and Barr (1968)*. The Canadian range of the species covers approximately 4,500 km^2 (1,737 mi.^{2}) an area of about 300 km (186 mi.) long but only 10-30 km (6.2-18.6 mi.) wide *(Guiasu et al., 1996)*. The northern limit of the species appear to be about 43°N although one anomalous record exists from northern Ontario (Rainy River District near Atikokan, 48°N) *(Crocker and Barr, 1968)*. The limited distribution of this species in Canada is probably a function of the combination of possible competition with the more abundant and closely related Chimney Crayfish and as yet unidentified environmental constraints *(Crocker and Barr, 1968; Guiasu et al., 1996)*.



North America – The species is wide ranging in the southern half of North America. It is found in Ontario, Michigan, Minnesota, Wisconsin, Ohio, Pennsylvania, Kentucky; Delaware, Illinois, New York, New Jersey, Indiana, Maryland, District of Columbia, West Virginia, Tennessee, North Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Arkansas, Missouri, Iowa, Nebraska, Kansas, South Dakota, North Dakota, Oklahoma, Texas, Colorado, Wyoming and Montana *(Hobbs, 1989; Page, 1985; Taylor et al., 1996)*.

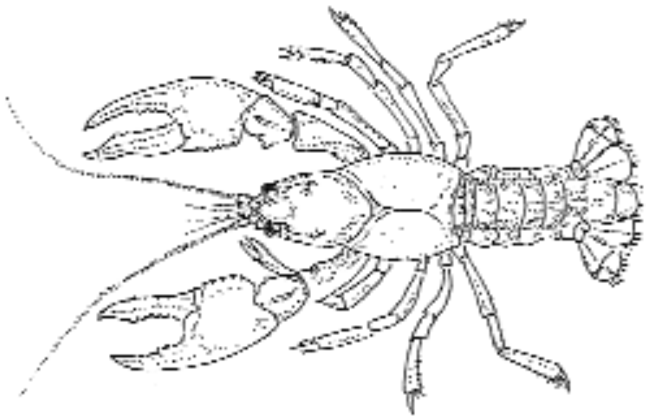


FIGURE 3: *Black and white drawing of the Devil Crawfish (Cambarus diogenes) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

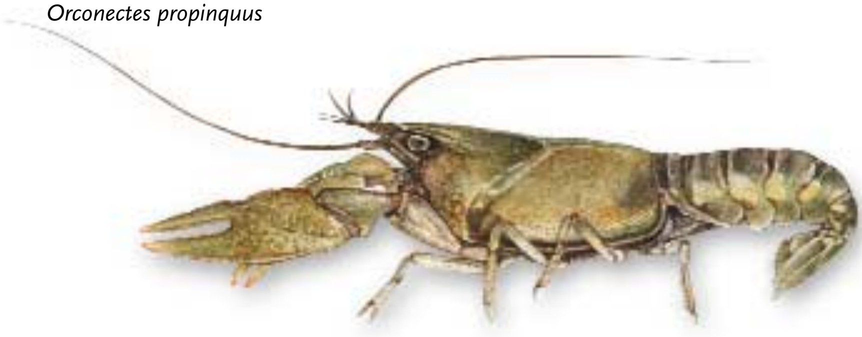
HABITAT AND ECOLOGY: The Devil Crawfish appears to be an obligate burrower in Ontario, constructing burrows in coastal wetlands, mudflats, wet meadows and marshes *(Crocker and Barr, 1968; Guiasu et al., 1996)*. The burrows are usually capped with mud chimneys, but these may not be present where the ground is very soft and moist. In Ontario, burrows are generally shallower than those of Chimney Crayfish. The chimneys may be quite high (up to 15 cm/5.85 in.) and the diameter of the burrows may be very large depending upon the size of the occupant *(Hamr, unpublished)*. Oxygen concentrations of burrow water can range between 0.1-8.8 mg/l (0.1-8.8 ppm); temperature 17-27˚C (63-81˚F); pH from 5.2-9.0) *(Hobbs III and Jass, 1988)*. Devil Crawfish can take oxygen directly from the air by exposing its gills to the air-water interface or crawling into chimneys and/or tunnels which are above the water table. It can also survive in air for prolonged periods as long as its gills are covered by a thin film of moisture. Although it lives in similar habitats, the Devil Crawfish has never been found together with Chimney Crayfish in Ontario *(Guiasu et al., 1996)*.

LIFE HISTORY: Little is known of the life history of this species in Ontario as no published studies exist. Copulation can occur within burrows or in open water. *Hamr (unpublished)* found Form I males and females with strong glair gland development in early May and also observed oviposition in captivity at that time. He also observed moulting activity in adults in August. Maturity is reached probably at CPLs in excess of 40 mm (1.56 in.), and maximum size is 61 mm (2.38 in.) CPL.

CONSERVATION STATUS: The range of this species overlaps areas of intense agricultural and recreational activity and, as in the case of the Chimney Crayfish, its habitat is likely under threat because of wetland destruction and alteration. To prevent further habitat shrinkage, populations of this species should be identified and their habitats should be protected. Because of the vulnerability of their habitat Devil Crawfish should be classified as "Vulnerable" in Canada. It is fortuitous that one of the known distribution points is found within a federally protected area (Long Point National Wildlife Area – Canadian Wildlife Service).

NORTHERN CLEARWATER CRAYFISH

Orconectes propinquus



Found in a variety of habitats. It can be found in small muddy or rocky streams, large rivers as well as shallow ponds and deep lakes.

DESCRIPTION: This species, Ecrevisse a Rostre Careen, is the smallest of the Canadian species. It is easily identified by a prominent rostral carina. Colouring is basically brown-green with a broad dark mid-dorsal stripe on abdomen and chela with orange tips. An unusual white morph of this species has been found in Lake Simcoe *(Dunham et al., 1979; Jordan and Dunham, 1980)*.

DISTRIBUTION: Canada/Ontario – The Northern Clearwater Crayfish is found only in Ontario and Quebec. In Ontario it occurs from the eastern shore of Lake Superior north to the Moose River drainage (James Bay) and south to Lake Huron, Ontario and Lake Erie *(Crocker and Barr, 1968; Corey, 1987a, 1987b; 1988; David et al., 1994; Somers and Green, 1993; David et al., 1997)*. It has also apparently been introduced into northwestern Ontario (Nipigon River, Burditt Lake and Lake of the Woods near the Sioux Narrows) where it appears to be spreading *(Crocker and Barr, 1968; Momot pers. comm.; Schueler pers. comm.)*. In Quebec its distribution remains unclear but it has been collected from the St. Lawrence river (at Montreal), Ottawa River and its northern tributaries (Ottawa region), Lake Dunford, Riviere Kinjevis and lac Kipawa. The species is also thought to be found throughout the region north of the St. Lawrence River *(Dube pers. comm.)*.

North America – This species range centers in northeastern North America.
It occurs in Ontario, Quebec, New York, Vermont, Massachusetts, Pennsylvania, Ohio, Iowa, Illinois, Indiana, Michigan, Wisconsin and Minnesota *(Page, 1985; Hobbs III et al., 1989; Taylor et al., 1996)*.

HABITAT AND ECOLOGY: The Northern Clearwater Crayfish is found in a variety of habitats *(Berrill, 1978)*. It can be found in small muddy or rocky streams, large rivers as well as shallow ponds and deep lakes. When on sandy, rocky or gravelly substrate it digs shallow depressions under rocks or woody debris but like many other "open-water" species, it is capable of constructing extensive burrow networks in clay bottomed streams where cover is scarce *(Berrill and Chenoweth, 1982; Hamr, 1984; Hamr and Sinclair, 1985)*.

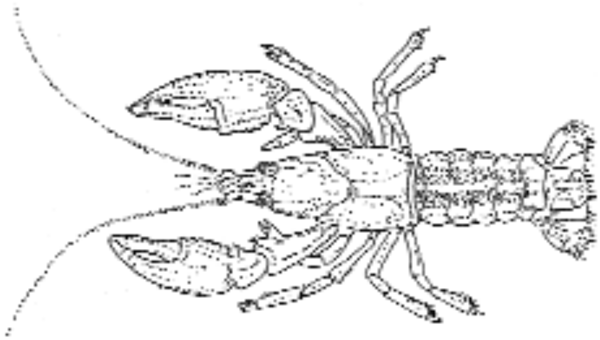


FIGURE 4: *Black and white drawing of the Northern Clearwater Crayfish (Orconectes propinquus) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

In Ontario, populations of Northern Clearwater Crayfish have been found in warmer lower elevation, higher pH and more eutrophic lakes, as well as lakes having shallower maximum depths (*David et al., 1997*). The activity (and trapability) of this species appears to be affected by predatory fishes such as bass (*Collins et al., 1983*). Laboratory studies have shown this species to have a fairly high station holding capacity (35 cm/sec or 13.7 in./sec) in fast currents which is likely to enable it to live in fast flowing streams (Maude and Williams, 1983). In Ontario, the Northern Clearwater Crayfish has been found together with the Appalachian Brook Crayfish, the Robust Crayfish, the Virile Crayfish, the Papershell Crayfish, the Obscure Crayfish and the Rusty Crayfish.

LIFE HISTORY: In Ontario populations, mating occurs from mid July to September and again in early April, eggs are laid from late April to early June (water temperature > 5˚C/41˚F) and are carried for 4-6 weeks. Hatching takes place from mid-May to mid-July and young are carried for about 2 weeks. Maturity is generally attained at 16-20 mm (0.62-0.78 in.) CPL but the minimum size of maturity is 13 mm (0.51 in.) CPL. The average adult size is 23 mm (0.9 in.) while the average lifespan is 2 years. The largest specimen recorded is 35 mm (1.37 in.) CPL and the maximum life span is 3-4 years old. Moulting takes place throughout the summer in immature crayfish. Mature males moult to Form II in May and then back to Form I in Mid July. Mature females moult once in July *(Crocker and Barr, 1968; Berrill, 1978; Corey, 1987a, 1987b, 1988)*. Maturity is attained at about 20 mm (0.78 in.) CPL and the maximum recorded size is 45 mm (1.76) CPL *(Page, 1985)*.

CONSERVATION STATUS: Although generally widespread in its Canadian range, it has recently faced severe competition for resources by invading or expanding species. In Ontario, the Rusty Crayfish which is closely related and occupies a similar niche, has eliminated this species from numerous watersheds in the south and north of the province *(Berrill, 1978; Corey, 1988; Olsen et al., 1991; Barr, 1996; Hamr, 1997a; Momot, 1997)*. The Rusty Crayfish is larger, more aggressive, and has a greater fecundity as well as faster egg and larval development than the Northern Clearwater Crayfish *(Corey, 1988)*. Competition between the two also occurs via hybridization and reproductive interference *(Capelli and Capelli, 1980; Berrill, 1985; Schueler, 1988; DiDonato and Lodge, 1993; Gunderson, 1995; Hamr 1997a; Momot, 1997)*.

Local declines and disappearance may also be due to water and air pollution and associated chemical changes in previously occupied watersheds. A study of crayfishes in lakes of the Canadian Shield in Ontario found decreases in the Northern Clearwater Crayfish as well as other native populations. It was suggested that these declines may be linked to low pH and high aluminum concentrations *(David et al.,1994)*. Other studies showed that the Northern Clearwater Crayfish is absent in lakes with pH < 5.6 and that water at a pH of 5.4-6.1 is toxic to attached juveniles of this species and the Rusty Crayfish *(Berrill et al., 1985)*. Since the Northern Clearwater Crayfish is much less tolerant of acid conditions than either the Appalachian Brook Crayfish and the Robust Crayfish, the disappearance of this species (in the absence of other negative factors) may be a good indicator of lake acidification.

There appear to still exist many secure and dense populations of this species in Ontario. Local extirpation, however, appears to be an increasing problem. Given the widespread, fast and continued expansion the Rusty Crayfish in eastern Canada the southern populations of Northern Clearwater Crayfish should be considered locally threatened or in some cases endangered. Although there are many threatening factors acting on this species, given its apparent widespread distribution and abundance his species should be considered as "Vulnerable" in Canada.

OBSCURE CRAYFISH

Orconectes obscurus

Found in lakes, rivers and streams. Little information is available on the ecology of the Obscure Crayfish, but it appears to occupy the same ecological niche as the native Northern Clearwater Crayfish.

DESCRIPTION: A small crayfish that is olive-grey-brown dappled with dark brown in colour with characteristic dorsal crescent pattern near back edge of carapace. It is distinguished from the similar Northern Clearwater Crayfish by absence of rostral carina and from the Rusty Crayfish by male copulatory stylet morphology and absence of rusty markings on body.

DISTRIBUTION: Canada/Ontario – The species occurs only in Ontario where it was probably introduced in the same manner as the Rusty Crayfish since most locations coincide with cottage, recreational and sport fishing areas *(Crocker and Barr, 1968)*. It has been found in several lakes and rivers from eastern Ontario (Lucky Lake near Plevna), to the Kawartha Lakes (Chandos, Kasshabog, Round Lakes and North River) and northcentral Ontario (Rock and Cedar Lakes in Algonquin Park; Dropledge Lake, Madawaska River in Renfrew County; Oldmans, Black, Simmons, Bells, Himbury and Crawford Lakes east of Parry Sound) as well as north west in the Manitoulin region (Cutler and Maple Lakes near Massey) *(Crocker and Barr, 1968; Berrill, 1978; David et al., 1997)*. There is also an unconfirmed record for the Obscure Crayfish in the Mississippi River (East Ontario) at Ferguson Falls *(Schueler pers. comm.)*.

North America – the natural range of this species is small, centering on the Ohio River valley and the states of Ohio, New York, Maryland, Pennsylvania, Virginia and West Virginia. It has also been introduced into Ontario, Maine, Massachusetts, Vermont and Tennessee *(Hobbs et al., 1989; Taylor et al., 1996)*.

HABITAT AND ECOLOGY: In the Kawartha Lakes region, it has been found in rivers and lakes under rocks, gravel and boulders *(Berrill, 1978)*. Laboratory studies have shown this species to have only moderate station holding capacity (40 cm/sec or 15.6 in./sec) in fast currents which may prevent it from colonizing the upstream portions of faster flowing rivers and streams *(Maude and Williams, 1983)*.

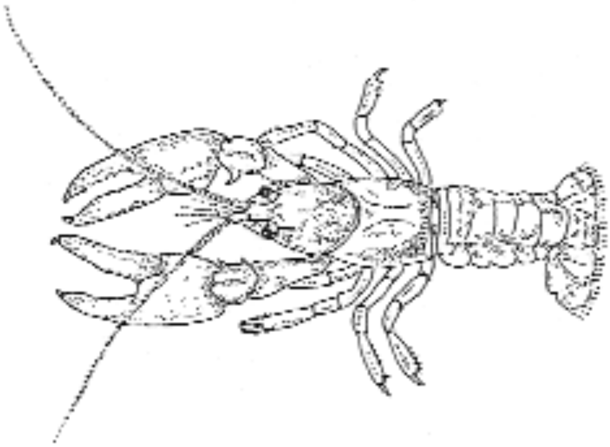


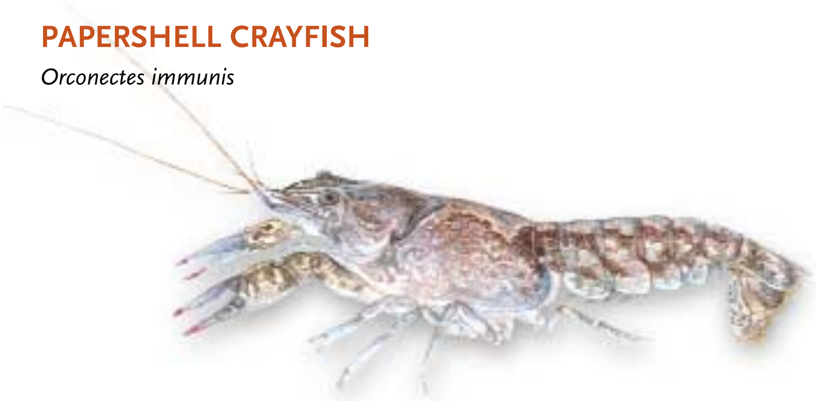
FIGURE 5: *Black and white drawing of the Obscure Crayfish (Orconectes obscurus) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

LIFE HISTORY: Little is known of the life history of this species in Canada. In the Kawartha Lakes region of Ontario, the populations appear to conform to the general orconectid type life history pattern. In Ohio and Pennsylvania populations, copulations occurred from mid-August through November, eggs were laid in spring (April), hatching occurred in May and free-living young of the year were first seen in late June. *(Fielder, 1972; Ortmann, 1906)* One year old crayfish ranged from 18-34 mm (0.7-1.33 in.) CPL, whole 2 year olds ranged from 38-40 mm (1.48-1.56 in.) CPL. Males moulted from Form I to Form II in May and back to Form I in early June and mature females moulted after their young left *(Fielder, 1972)*. The average lifespan was 2 years.

INTRODUCTION STATUS: As is the case with the Rusty Crayfish, the Obscure Crayfish appears to be spreading in Ontario. Since the original records *(Crocker and Barr, 1968)*, new distribution points have been found in numerous lakes and rivers *(Berrill, 1978; David et al., 1997)*. This includes populations from the Canadian Shield suggesting that, unlike the Rusty Crayfish, this species can spread into that geographical region despite any possible environmental constraints. The Obscure Crayfish has been found together with the Rusty Crayfish, the Papershell Crayfish, the Appalachian Brook Crayfish and the Robust Crayfish *(Berrill, 1978; David et al., 1997)*. Both *Berrill (1978) and David et al. (1997)* found that in some of the watersheds they surveyed the Obscure Crayfish was the sole species present, suggesting that it may have eliminated native species. This may be the result of direct competition but it is also believed that hybridization between the Obscure Crayfish and the Northern Clearwater Crayfish can occur. Although it does not appear to be as invasive and prolific as the Rusty Crayfish, it still is important to monitor the spread and impact of this species in Ontario. This is particularly crucial on the Canadian Shield where the Rusty Crayfish appears to have little impact to date.

PAPERSHELL CRAYFISH

Orconectes immunis

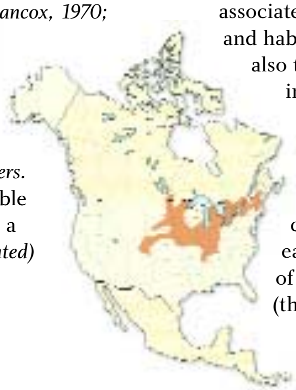


Found in slow moving streams, ponds and lakes, marshes and roadside ditches. It can construct deep burrows and as a result is able to survive in temporary waters.

DESCRIPTION: The Papershell Crayfish is also commonly known as the Calico Crayfish; ecrivisse-calicot. It is a small to medium-sized crayfish that is slender and fragile looking. It is distinguished from other orconectids by notch at base of inner side of dactyl of chela. Colouring is olive- green to brown with characteristic dorsal mottled pattern and no colour bands on tips of chela.

DISTRIBUTION: Canada/Ontario – The documented Canadian range of this species appears to center on southern Ontario *(Crocker and Barr, 1968; Berrill, 1978; David et al., 1997)* but it has also been found in northern Ontario (Crab Lake, Sudbury District and Snake Bay in Lake of the Woods) and Quebec (parc de al Verendrye and the Laurentides region), as well as in Manitoba (Red River drainage south of Winnipeg) *(Popham and Hancox, 1970; Dube and Renaud, 1994; Schueler unpublished)*. It is suspected that the Quebec records may be a result of introductions by New York anglers *(Dube pers. comm.)* but it is also possible that the species may have a much broader *(undocumented)* distribution in Canada.

North America – This species range is in the northeast and midwest of North America. It is found in Quebec, Ontario, Manitoba, Vermont*, New York, New Hampshire, Maine*, Rhode Island*, Massachusetts*, Connecticut*, Michigan, Ohio, Wisconsin, Illinois, Kentucky, Tennessee, Alabama, Mississippi, Indian, Minnesota, Iowa, Missouri, Arkansas, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Montana, Wyoming and Colorado *(Hobbs, 1989; Taylor et al., 1996)* (*indicates suspected/known introduction).



HABITAT AND ECOLOGY: The substrate in the habitats of this species is generally soft mud or clay with abundant aquatic vegetation *(Crocker and Barr, 1968; Berrill, 1978)*. This species is thought to be tolerant of low oxygen concentrations often associated with certain types of pollution and habitat alteration *(Page, 1985)*. It can also travel across dry ground, especially in wet weather and is thus able to move from pond to pond *(Crocker and Barr, 1968)*. Burrows are mostly simple but can be more complex and capped with chimneys. This makes its presence easily confused with the occurrence of the other two burrowing species (the Chimney Crayfish and the Devil

PAPERSHELL CRAYFISH

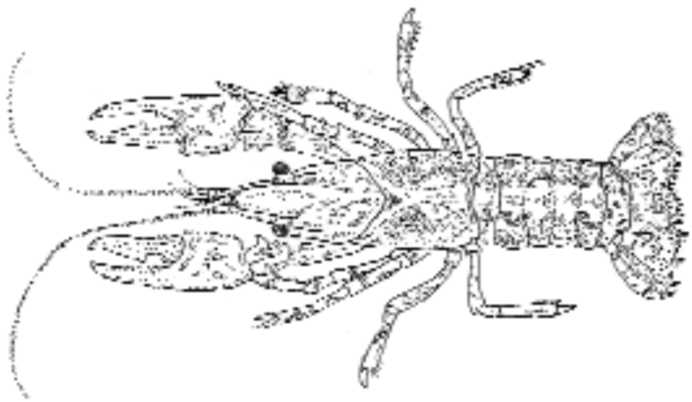


FIGURE 6: *Black and white drawing of the Papershell Crayfish (Orconectes immunis) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

Crawfish). Like the other burrowing species, the Papershell Crayfish has a preference for soft substrates and a low ability to hold station in currents faster than 26 cm/sec (10.1 in./sec), the lowest slip-speed value of Canadian crayfishes tested *(Maude and Williams, 1983)*. These factors are likely to exclude it from colonizing faster flowing rocky streams. In Ontario, this species occurs together with the Appalachian Brook Crayfish, the Chimney Crayfish, the Northern Clearwater Crayfish the Rusty Crayfish, the Virile Crayfish and the Obscure Crayfish *(Berrill, 1978; David et al., 1996; Hamr unpublished data)*.

LIFE HISTORY: Little is known about the life history of Canadian populations of the Papershell Crayfish. In Chemong Lake, southern Ontario, ovigerous (mature) females ranged in CPL from 32-44 mm (1.25-1.72 in.) while Form I (mature) males ranged from 30-48 mm (1.17-1.87 in.) CPL *(Berrill, 1978)*. Few females carrying eggs were found in late summer and autumn suggesting that some females may extrude eggs in the fall and carry them over winter *(Berrill, 1978)*. Hatching probably occurs in May and Ontario *(Crocker and Barr, 1968)*. Form I males were found in April, July and August *(Crocker and Barr, 1968)* and Form II in June.

Hatching occurs from April to early June and young reach CPLs of 13-29 mm (0.51-1.13 in.) by the end of the first summer. Some become mature at this time but most do not reach maturity until the following spring. Males are in Form I from July to June and in Form II in May and June *(Crocker and Barr, 1968)*. The average life span is 2-3 years and maximum recorded size is 49 mm (1.91 in.) CPL *(Page, 1985)*.

CONSERVATION STATUS: Like the other burrowing species, the Papershell Crayfish is found in many habitats which are vulnerable and subject to pressure from agriculture and urbanization. However, its Canadian range is somewhat broader than those of the other two "burrowing" species due to the fact that it is not an obligate burrower and has a broader ecological niche and distribution. The physiological tolerance of the Papershell Crayfish to both organic pollution and low oxygen requirements allows this species to occupy habitats that would be unsuitable for less tolerant crayfish species. As such, this species should therefore be considered "Currently Stable".

COMMERCIAL EXPLOITATION: This species, given its small size and thin exoskeleton are thought to be the most important live bait crayfish species in the northern United States and Canada. Individuals are preferred items of both anglers and game fish alike. It has been estimated that 175 metric tonnes of crayfish (primarily Papershell Crayfish) are cultivated annually for the baitfish industry in the northern United States *(Huner, 1989, 1997)*. Despite this figure, there remains a very high demand for soft-shelled Papershell Crayfish as fishing bait in both the United States and Canada *(Huner, 1997)*. Other crayfish species such as the Virile Crayfish and the Rusty Crayfish, which are harvested for human consumption, tend to be far too large for fishing bait. In addition these species also have thicker exoskeletons which are not suitable as fishing bait when compared to the smaller and thinner shelled Papershell Crayfish *(Momot, 1988; Huner, 1997; Brown and Gunderson, 1997)*.

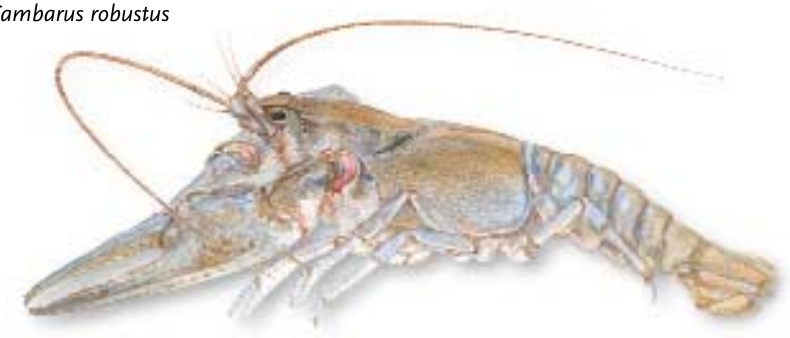
Due to its small size, this species is not able to obtain food size for human consumption in one growing season in the northern parts of its range and at commercially viable densities *(Brown and Gunderson, 1997)*. As such, young-of-the-year (YOY) are generally used as a recreational fishing bait. However, this species may reach food size for human consumption by the end of their second growing season. In one particular study, Papershell Crayfish harvested throughout the summer in a Michigan pond produced between 776-911 kg/ha (693-813 lb/ac). This yield was comparable to the average yield of 569 kg/ha (466 lb/ac) in Louisiana crayfish ponds *(Brown and Gunderson, 1997)*. Interestingly, although given its reputation as a smaller crayfish species, Papershell Crayfish from this pond had higher tail meat yield than comparable Northern Clearwater Crayfish or Virile Crayfish.

In Minnesota (USA) there are two basic culture systems currently in use for the rearing and culture of the Papershell Crayfish. The first is small outdoor production ponds and the second is wild rice production ponds *(Forney, 1957; Gunderson and Brown, 1997)*. In an investigation by Forney (1957), Papershell Crayfish were observed being raised in outdoor ponds in New York. These ponds ranged in size from 0.015-2.27 ha (0.037-5.61 ac.). In his study, Forney suggested that ponds under 0.23 ha (0.57 ac.) be used for the rearing and culture of Papershell Crayfish as they are thought easier to manage (e.g. vegetation control) and seine. The depths of these particular ponds in New York were between 1.8-3.1 m (5.9-10.2 ft.). Such a depth was thought to provide good over wintering conditions by not freezing solid to the bottom and subsequently causing winterkill. In contrast, *Brown and Gunderson (1997)* state that ponds with depths of only 34 cm (1 ft) produce excellent yields of Papershell Crayfish in Minnesota. Such ponds should be stocked in the fall with 1,500-2,500 mature crayfish per hectare or in the spring with 750-1,259 carrying females (berried). Young Papershell Crayfish in the northeastern United States reach bait size by July and are best removed from production ponds by seining. Fertilization is also recommended in order to improve crayfish growth and survival by increasing primary productivity in such ponds *(Forney, 1957; Brown and Gunderson, 1997)*.

In Minnesota wild rice paddies, Papershell Crayfish have been observed to begin burrowing behaviour from early July through until winter freeze up. However, the majority of crayfish were observed to burrow during the last 2 weeks of August even though water quality and levels were maintained *(Brown and Gunderson, 1997)*. Such burrowing activity is most likely related to both ambient water temperature and photoperiod. Seining is thought a more effective method of harvesting crayfishes from wild rice paddies. Mature Papershell Crayfish in Minnesota wild rice paddies were observed to be unavailable after September 1st. Crayfish were observed to emerge from their over-winter burrows shortly after the wild rice paddies are flooded in the spring. Many egg-carrying females also emerge at this time. However, these females do not lay their eggs until later in the spring/early summer. Unlike the majority of other orconectid species, egg carrying female Papershell Crayfish enter traps freely and trap as easily as males *(Brown and Gunderson, 1997)*.

ROBUST CRAYFISH

Cambarus robustus



Appears to be tolerant of pollution. The species can survive in acidic lakes and in polluted urban streams with heavy sediment input. It is found is most of the streams flowing into Lake Ontario from Toronto to Niagara.

DESCRIPTION: The Robust Crayfish is also known as Ecrevisse robust. It is a large crayfish with strong chelae and colour is basically greenish-brown. It is distinguished from similar species the Appalachian Brook Crayfish by larger adult size, more elongate rostrum and double row of tubercles on inner border of palm of chelipeds.

DISTRIBUTION: Canada/Ontario – This species is found in Ontario and Quebec. In Ontario, where its distribution has been well documented, it is found from Lake Temagami in the north, westward to the eastern shore of Georgian Bay, south to the western end of Lake Erie and east to the upper Trent River drainage *(Crocker and Barr, 1968; Berrill, 1978; David et al., 1997; Guiasu et al. 1996; Hamr and Berrill, 1985)*. In Quebec it has been recorded only in the following two southeast locations: Ruisseau Kennedy in Papineau county and Rapides des Cedres on the Riviere du Lievre *(Dube and Provost, 1990)*. These populations are well established but it is not certain whether they are an extension of the natural distribution or the result of an introduction.

North America – This species' range centers on the Great Lakes-Ohio River drainages and is found in Quebec, Ontario, New York, Connecticut, Pennsylvania, Michigan, Ohio, Kentucky, Tennessee, Indiana, Virginia, West Virginia and North Carolina.

HABITAT AND ECOLOGY: The Robust Crayfish often occurs in or adjacent to areas of high flow such as rapids and waterfalls *(Crocker and Barr, 1968; Bousfield, 1969; Berrill, 1978; Hamr, 1983; Dube and Provost, 1990; Guiasu et al., 1996)* and studies have shown that it can hold on to substrate in current speeds of 50 cm/sec – a value significantly higher than that for any other crayfish species found in Ontario *(Maude and Williams, 1983)*. The Robust Crayfish usually constructs shallow burrows under larger stones on rocky and gravelly substrates but it can also be found on silt and mud *(Crocker and Barr, 1968; Hamr, 1983)*. The species appears to be tolerant of pollution as it can survive in acidic *(Taylor et al., 1995)* lakes and in polluted urban streams with heavy sediment input.

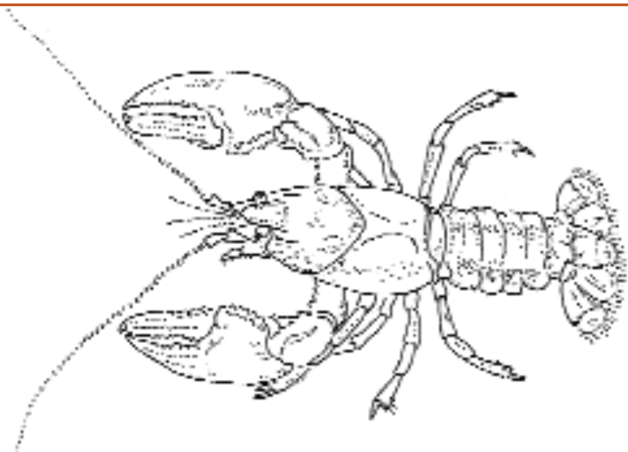


FIGURE 7: *Black and white drawing of the Robust Crayfish (Cambarus robustus) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

Despite its larger size, the presence of predatory fish affects the activity and trapability but not the density of this species *(Collins et al., 1983)*. The Robust Crayfish is a large and aggressive species which has been shown to be clearly dominant in aggressive interactions with the Appalachian Brook Crayfish which in turn is generally more aggressive than the Canadian orconectids *(Guiasu and Dunham, 1997)*. In Canada, the Robust Crayfish has been found together with the Appalachian Brook Crayfish, the Northern Clearwater Crayfish, the Virile Crayfish, the Obscure Crayfish, the Papershell Crayfish and the Rusty Crayfish *(Berrill, 1978; Hamr 1983; David et al., 1997)*.

LIFE HISTORY: In Ontario, reproduction appears to take place in the summer. Mature females show strong glair gland development from May to August while copulation has been observed in June in the field and June to early July in captivity *(Hamr and Berrill, 1985)*. Females with eggs are found from June to July and with young from July to September. Most females lay their eggs by mid-July and the peak of hatching occurred in early August after about 30 days. The young undergo two moults in their metamorphosis, spending about 22 days attached to their mothers and then become free-living in mid to late August. In some central Ontario populations, females with stage 3 young were collected in September, October and April suggesting that young may be carried over winter and released in the following spring *(Corey, 1990)*. Moulting occurs from May to September and immature crayfish reach 17-26 mm (0.66-1.0 in.) CPL by the end of the second summer. Most individuals mature at 2 years of age. However some may not reach maturity until 3 years of age which is the average life-span of the species *(Hamr and Berrill, 1985)*. Adults of both sexes moult in September. Form I and Form II individuals are present throughout the year *(Berrill, 1978; Hamr and Berrill, 1985; Corey, 1990)*. The maximum life span is 4 years and the maximum recorded size is 57 mm (2.22 in.) CPL.

CONSERVATION STATUS: The Robust Crayfish appears to tolerate pollution as its distribution overlaps highly industrialized areas of southern Ontario where it survives in urban streams with high sediment and pollutant loadings *(Jain and Hamr, 1996)*. It is also among the most acid-tolerant of the freshwater crayfishes tested, which explains its presence in acid stressed lakes of north-central Ontario *(Taylor et al., 1995)*. Juveniles of this species are able to survive in water with pH as low as 4.0 *(Berrill et al., 1985)*. The Robust Crayfish is a large and aggressive species and, given its apparent expansion in Ontario and Quebec during the past 30 years, it appears that this species has the potential to competitively exclude other species when competing for limited resources *(Guiasu and Dunham, 1997)*. It is not clear whether the introduced and rapidly expanding Rusty Crayfish can successfully compete with or eliminate the Robust Crayfish from its habitat, but regardless of the outcome of the interaction between the two, the Robust Crayfish should be able to survive in the more acidic waters of the Canadian Shield where the Rusty Crayfish appears to be excluded. Due to its abundance and its ability to cope with various pollutants as well as competitors, the Robust Crayfish remains common within its range and must therefore be considered to have a "Currently Stable" status in Canada.

RUSTY CRAYFISH

Orconectes rusticus rusticus

Occurs in lakes, rivers, streams and ponds. The Rusty Crayfish prefers areas that offer rocks, logs, or other debris as cover but substrate types may also include clay, silt, sand and gravel. It can inhabit slower, deeper pools as well as shallow fast water areas of streams.

DESCRIPTION: A medium to large crayfish. It has a brown cephalothorax and abdomen, green claws with dark black bands near tip, green legs, prominent (dorso-lateral) rusty spots on each side of the carapace and small rusty spots also present on abdominal segments. A blue morph of this species has been recorded in Ontario *(Hamr, unpublished data)*. It can be distinguished from the similar Northern Clearwater Crayfish by absence of rostral carina and presence of rusty markings on exoskeleton. The other similar native species, the Virile Crayfish, is generally more blue in colour (without rust markings) with broader shorter chelae bearing distinct yellow tubercles, whereas the Rusty Crayfish has larger more elongated fingers of claws without tubercles.

DISTRIBUTION: Canada/Ontario – This species has been introduced to various locations in southern and northwestern Ontario. Since it is established in the Lake of the Woods and the Ottawa River drainage *(Momot, 1992; Schueler, 1988)*, it is likely that it has or will in the near future also invade Manitoba and Quebec. Its distribution within Ontario appears to be spreading continuously though more introductions as well as the through the spread of current populations. Ontario drainages/regions which have been colonized by this species include; the Magnetawan River between Emsdale and Kearney *(Lloyd – Gottinger, pers. com.)*, Lake of the Woods, Quetico Provincial Park (Basswood Lake), Lake Superior and its tributaries near Thunder Bay (Needing-MacIntyre, Pigeon Lake, Portage Little Pine, Kaministiquia and Jackfish Rivers; lakes Pounsford, Lenore and Wiswell), Eramosa River (near Guelph), Berford Lake (on the Bruce Penisnula); the region from the east edge of Toronto (Rouge River and Duffin Creek) to Plevna in eastern Ontario (Shaw and Plevna Lakes) north through the Kawartha Lakes (from Rice Lake north to Balsam Lake) into Haliburton (Head, Kashagawigamog and Drag Lakes) and east to the Jock and Rideau rivers confluence *(Crocker and Barr, 1968; Berrill, 1978; Corey, 1988; Maude, 1988; Schueler, 1988; David et al., 1994; Karstad, 1995; Hamr, 1997; Momot, 1992; Momot, 1997)*. It is also now widespread in the upper Mississippi drainage in Lanark and Frontenac counties, the lower Trent system *(Schueler, pers.comm., 1988)* and Rouge River *(Hamr, unpublished)*.

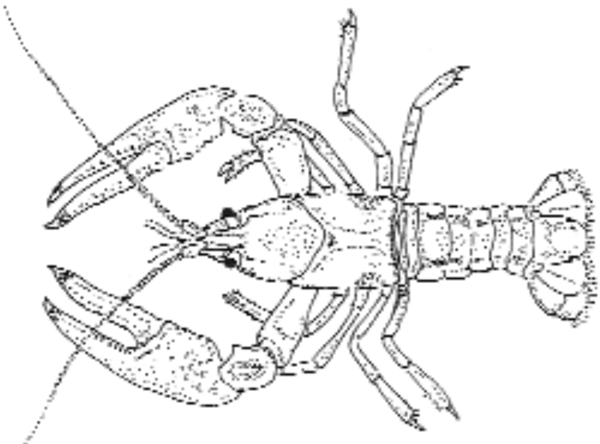


FIGURE 8: *Black and white drawing of the Rusty Crayfish (Orconectes rusticus rusticus) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

North America – The Rusty Crayfish is thought to be native to the Ohio River Basin and the state of Ohio, Kentucky, Michigan and Indiana. However, this species has been widely introduced in North America and is now found in Ontario, Illinois, Tennessee, Missouri, West Virginia, Iowa, Minnesota, New York, New Jersey, Pennsylvania, Wisconsin, Vermont, Massachusetts, Connecticut, Maine, New Hampshire and New Mexico *(Gunderson, 1995; Page 1985; Taylor et al., 1996)*.

HABITAT AND ECOLOGY: Rusty Crayfish generally do not dig burrows (except for shallow excavations under rock and stones) but have been observed to construct extensive and quite deep burrows in a clay bottomed Ontario stream *(Hamr, 1997a)*. This species appears to need permanent lakes or streams that provide suitable water quality year round. Rusty Crayfish, especially juveniles, feed heavily on benthic invertebrates and it has been estimated that this species can consume twice as much food as similarly sized Virile Crayfish because of a higher metabolic rate *(Momot, 1992; Jones and Momot, 1983)*. Rusty Crayfish are therefore more likely to compete with juvenile game fish and forage species for benthic invertebrates than are native crayfish species.

LIFE HISTORY: In southern Ontario, the species has been shown to breed very early in spring (March-April) when water temperatures rise above 4˚C (39˚F). Eggs are laid 11-12 days after copulation and are carried for 6-8 weeks. The fecundity ranges from 35-351 and eggs are about 2.4 mm (0.094 in.) in diameter *(Berrill and Arsenault, 1982; Corey, 1987, 1988)*. The average fecundity and egg volume of this species is greater than that of the native Virile Crayfish and Northern Clearwater Crayfish *(Corey, 1987)*. Males moult for Form I to Form II in May and then back into Form I in June-July *(Corey, 1988; Momot, 1991)*.

The Rusty Crayfish grows rapidly with maturity being reached early in both sexes, in some cases at the end of the first summer of life and young Rusty Crayfish then may participate in mating within less than a year of hatching. Maturity is attained between 14-23 mm (0.63-0.9 in.) CPL and the maximum life span is 3-4 years at a carapace length of 40-45 mm/1.6-1.8 in. *(Berrill, 1978; Corey, 1988; Momot, 1991; Hamr, 1997a)*. Maximum size measured to date is 54 mm CPL *(Momot, 1997)*.

In southern Ontario densities may reach very high numbers – average densities of 6-64 crayfish per m^2 (1.2 $yards^2$) have been counted in rivers draining into Rice Lake (maximum counts as high as $113/m^2$ or

371/ft^2). The sex ratio is about 1:1 but adult males are generally more active throughout and therefore make up the majority of hand samples and trap catches (88% of total) *(Hamr, 1997a)*.

INTRODUCTION STATUS: The Rusty Crayfish is thought to have been introduced into Ontario in the early 1960s presumably by anglers from Ohio *(Crocker and Barr, 1968)*. The probable introduction point is in the Kawartha Lakes where it has been first reported – its densities are the highest documented (up to 113/m^2 or 371/ft.^{2}) and it is the dominant or sole occupant of many watersheds *(Hamr, 1997a)*. It is an aggressive species and a prolific breeder which, as a result, has spread significantly in Ontario, and has displaced resident native species (Virile Crayfish, Northern Clearwater Crayfish and Appalachian Brook Crayfish) in numerous lakes and waterways in the south and north of the province of Ontario *(Berrill, 1978; Corey, 1988; Momot, 1992; Hamr, 1997a; Hamr, 1997)*. *Barr (1996)* noted that when the available records for Rusty Crayfish in southern Ontario are mapped it is more likely that the south-most of the two points of introduction identified by Crocker and Barr in 1968 has given rise to the currently observed range by a process of gradual outward diffusion. During the same time period, the species has been observed to extend its range in Ohio, Illinois *(Page, 1985)* and Wisconsin *(Capelli, 1982)*, and thus appears to be in an expansive phase throughout its range. Similarly, *Momot (1997)* documented the rapid and continued spread of this species in the Thunder Bay region since 1991 and estimated its rate of expansion at about 1 km/year (0.62 mi./year). Given its presence and continued expansion in Lake of the Woods in the northwest and the Jock, Rideau and Mississippi drainages in the southeast, it is only a matter of time before the species enter the provinces of Manitoba and Quebec. In fact, specimens thought to be hybrids of Rusty Crayfish and Northern Clearwater Crayfish have been collected from Lake Heney near Gracefield, Quebec in 1980 *(National Museum of Nature unpublished record)*.

There appear to be few constraints on the ultimate range of the Rusty Crayfish in Ontario – the only barrier may be the Canadian Shield, whose physical and chemical character and/or harsh environmental conditions may prove limiting. Water ranging in pH from 5.4-6.1 was shown to be toxic to juvenile Rusty Crayfish in the laboratory *(Berrill et al., 1985)*. Beaver dams, weirs and waterfalls can also prevent or slow down the expansion within rivers *(Momot, 1997)*. Additionally, water temperatures play an important role in the rate of expansion as crayfishes are less active at cold temperatures (< 10°C/5°F). The southern warmer regions of Canada, where water temperatures are warmer for longer periods of the year, are therefore the most vulnerable to rapid invasion of the Rusty Crayfish. Laboratory studies have shown this species to have superior streamlining capabilities and station holding capability (40 cm/sec or 15.6 in./sec) which enables it to colonize the upstream portions of even fast-flowing rivers and streams *(Maude and Williams, 1983)*.

Where it has established itself, this species is an effective competitor and has often eliminated native species such as the Northern Clearwater Crayfish and the Virile Crayfish *(Momot et al., 1978; Capelli 1982; Lodge et al., 1986; Olsen et al., 1991; Hamr, 1997a; Momot, 1997)*. Larger size, earlier breeding season, higher fecundity, faster egg, larval and juvenile development appear to be some of the factors contributing to its dominance. In addition, the species may be able to better compete for food, withstand pressure from fish predation, and hybridize with closely related species such as the Northern Clearwater Crayfish *(Capelli and Capelli, 1980; Smith, 1981; Berrill, 1985; DiDonato and Lodge, 1993; Gunderson 1995; Lodge, 1997)*. It is not clear whether the Rusty Crayfish can successfully compete with or eliminate the Appalachian Brook Crayfish, the Robust Crayfish, the Northern Clearwater Crayfish, the Virile Crayfish, the Papershell Crayfish and the Obscure Crayfish. This shows that it's a potential threat to all species living in open water habitats in Ontario.

Therfore, the expanding dense populations of this species not only poses a threat to the biodiversity of the native crayfishes, but also potentially endangers other aquatic invertebrate fauna, aquatic vegetation as well as sport fish (in terms of competition for aquatic prey as well as predation upon fish eggs). Many of these effects have been well documented in the United States where the species has aggressively displaced native crayfishes and had a significant impact on aquatic ecosystems *(Capelli, 1982; Lodge et al., 1985; Olsen et al., 1991; Momot, 1992; Gunderson, 1995)*. One of the most serious impacts is the destruction of aquatic plant beds. Rusty Crayfish have been shown to reduce aquatic macrophyte abundance and diversity *(Lodge and Lorman, 1987; Olsen et al., 1991)*. This can be especially damaging in relatively unproductive northern lakes, where beds of aquatic plants are not abundant.

It will be difficult to control the spread of this species in Canada. None of the available chemical poisons can selectively kill the Rusty Crayfish without killing other crayfish species *(Gunderson, 1995)*. Intensive harvest will probably not eradicate this species, but may help reduce adult populations and minimize some impacts *(Hamr, 1997a)*. The most effective method of control is to prevent further introductions. Education of the general public (anglers, crayfish trappers, bait dealers and educators) about the threats posed by the Rusty Crayfish should help reduce the risk of spreading it to new areas within the country. It is very important to note that it is not necessary to introduce both a male and female crayfish to begin a new infestation. One female carrying viable sperm could begin a new population if released into a suitable environment *(Gunderson, 1995)*.

COMMERCIAL EXPLOITATION: Although it is abundant and common, and can occur at extremely high densities within its range, the Rusty Crayfish has not been used extensively for commercial purposes to date. There is however, a program underway in Minnesota that aims to utilize the introduced populations of Rusty Crayfish as well as possibly the native Virile Crayfish *(Minnesota Sea Grant, 1998)*. Given the large demand for crayfish in Scandinavia and the decline of native populations due to the crayfish plague, the Rusty Crayfish may be a good alternative source for the European market. Swedish importers have apparently shown interest in Rusty Crayfish more than 9 cm (3.5 in.) long *(Minnesota Sea Grant, 1998)*. Smaller crayfish may be suitable for processing as shelled tail meat and soft-shell production or could be grown to marketable size in culture ponds.

Crayfish production (for human consumption) can be divided into two distinct segments: hard and soft-shell production *(Huner and Romaire, 1990)*. Hard-shell producers market whole crayfish and tail meat while soft-shell producers market the entire body. Soft-shell production requires a steady source of market-size, hard-shell crayfish. Producing soft-shell crayfish involves harvesting hard-shelled crayfish from wild populations or aquaculture ponds and transferring them to an indoor, controlled moulting facility. Crayfish are then stocked into shallow tanks, fed and pre-moult individuals are identified and isolated in separate moulting tanks *(Culley et al., 1985)*. Researchers at Louisiana State University have also developed a recirculating soft-shell shedding system which can increase soft-shell crayfish production by five-fold. Soft crayfish are considered a delicacy and are also popular as fishing baits. Prices for soft crayfish sold as food range from $6-9 per 0.45 kg (1.1 lbs) *(Minnesota Sea Grant, 1998)*. However, culture and wild harvest of this as well as other invasive species (such as *O. limosus* in Quebec) must be approached with caution as the danger of further introductions and their effects on native populations must be addressed regionally. *Gunderson (1995)*, for example, warns that developing a viable commercial harvest of the Rusty Crayfish from natural lakes could be an incentive for unscrupulous trappers to plant them in other waters and suggests this may have contributed to the spread of the Rusty Crayfish in Wisconsin, according to Wisconsin DNR Fisheries.

Momot (1988) suggested that the Rusty Crayfish is large enough and locally abundant in northern Ontario to be of commercial interest. A recent pilot study of the potential for commercial exploitation of the dense introduced populations in the Kawartha Lakes in southern Ontario showed that the Rusty Crayfish can be harvested and sold commercially at competitive market prices in Ontario but more efficient and consistent harvest methods need to be developed *(Hamr, 1997, 1999)*. Hand harvesting, although it required relatively large physical effort, was the more efficient and consistent method of crayfish harvesting (Average catch per unit effort (CPUE): 50 crayfish ha-1) in shallow riverine habitats when compared to trapping which was efficient only at certain times of the year (Average CPUE = 6 crayfish trap-1; range 0-52 crayfish) *(Hamr, 1999)*.

The density of adult crayfish in the main harvest area in the Indian River near Peterborough, Ontario was estimated at 17 m-2. There appeared to be little or no decline in the abundance of harvestable animals (CLP > 37 mm/1.44 in.) over the 1-year period of the study in the major harvest areas of the Indian River. Harvested crayfish were held temporarily in small holding tanks, rinsed in well water, and processed using a Cajun-style method by boiling in spiced broth and deep freezing (in broth or drained). On average 20-22 crayfish of CLP length 36-44 mm (1.4-1.72 in.) made up 1 lb./0.45 kg (one crayfish: 25-29 g/0.88-1.02 oz.). The final product was sold to local restaurants and fish shops at $8 per 0.45 kg (1.1 lb).

It was suggested that aquaculture/farming in outdoor or indoor ponds may be a viable option to wild population harvesting given the explosive breeding capabilities of wild populations, tolerance to high temperatures (under oxygenated conditions), relatively fast growth rates and dense populations with large numbers of immature crayfish. Crayfish could also be trapped and grown out to marketable size and/or bred in captivity *(Hamr, 1999)*.

VIRILE CRAYFISH

VIRILE CRAYFISH

Orconectes virilis

Found in rivers, streams, lakes and ponds. The Virile Crayfish is able to survive severe weather conditions in the northern parts of its range.

DESCRIPTION: The Virile crayfish, Ecrivisse virile, is a medium to large crayfish. It is distinguished from similar species (the Papershell Crayfish) by broad flattened tuberculate chela with straight margin of dactyl, and male gonopod morphology. It has a olive-brown body that is dappled with dark brown, abdominal segments with dark brown medial spots and chelae and legs that are distinctly blueish with yellow tubercles. Blue colour morphs of this species have been recorded on occasion *(Momot and Gall, 1971)*.

DISTRIBUTION: Canada/Ontario – The Virile Crayfish is the most widely distributed crayfish species in Canada. It is found from eastern Alberta (Beaver, Amisk, North Saskatchewan and Battle Rivers), through Saskatchewan (Qu'apelle, Assiniboine River, Churchill and South Saskatchewan drainages), Manitoba (Assiniboine River, Lake Winnipeg, Manitoba and Winipegosis drainages), Ontario (Great Lakes to Hudson Bay) to Quebec (Ottawa River, St. Lawrence River drainage and north) *(Rawson and Moore, 1944; Aiken, 1968; Crocker and Barr, 1968; Vermeer, 1972; Talbot, 1985; Sawchyn, 1986; Clifford, 1991; Somers and Green, 1993; David et al., 1994, 1997; Dube pers. comm.)*. It is worth noting that Amisk River record in Alberta (54° 27′ 00″ N-111° 46′ 00″ W) is the northern-most record for any crayfish species in North America to date.

North America – This species is wide ranging in North America where it occurs in Quebec, Ontario, Manitoba, Saskatchewan, Alberta, New York, Michigan, Ohio, Kentucky, Illinois, Indiana, Minnesota, Wisconsin, Iowa, Missouri, Arkansas, Nebraska, Oklahoma, Texas, North Dakota, Kansas, Wyoming, Montana, Colorado and Utah. It has also been widely introduced throughout the United States (Alabama, Arizona, California, Connecticut, Maine, Massachusetts, Mississippi, Tennessee, Vermont, Virginia, West Virginia, New Hampshire, New Jersey, New Mexico, Pennsylvania and Rhode Island) as well as Mexico (Chihuahua) and Europe (France and Sweden) *(Hobbs, 1989; Hobbs III et al., 1989; Taylor et al., 1996)*.

HABITAT AND ECOLOGY: It is usually not found in swift flows or rapids *(Berrill, 1978)*. This species occurs most often on rocky substrate but it can also be found in slower flowing rivers on mud, silt and sand as well as in weedy soft bottomed lakes *(Berrill, 1978; Crocker and Barr,*

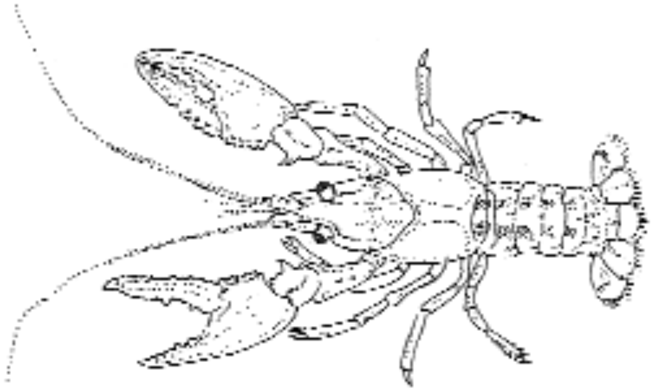


FIGURE 9: *Black and white drawing of the Virile Crayfish (Orconectes virilis) in dorsal view. Premek Hamr – artist, (from Hamr, 1998).*

1968). The Virile Crayfish lives in excavations under rocks but occasionally constructs extensive burrow networks in the banks of rivers such as those observed in the Wanapitei River *(Hamr, pers. comm.)*. On the Ontario Precambrian Shield, this species has been found in lakes with higher pH (> 5.7) *(David et al., 1997)*. It can also occur in deep water (up to 10 m/33 ft.) *(Crocker and Barr, 1968)*. The Virile Crayfish is able to survive severe weather conditions in the northern parts of its range. Survival in these conditions is not due to any special physiological adaptations but rather migration into deeper water and it is dependent on the presence of habitat where water does not freeze to the substrate at any time of year *(Aiken, 1968)*. Immature individuals apparently suffer higher winter-kills than adults because they do not migrate into deeper water like the adults. Laboratory studies have shown this species to have a preference for soft substrates and a fairly low station holding ability (28 cm/sec or 10.9 in./sec) in fast currents *(Maude and Williams, 1983)*. The Virile Crayfish appears to be most active from May to September and their trapability is influenced by water temperatures and presence of predatory fish *(Collins et al., 1983; Somers and Green, 1993)*. This species has been found together with the Appalachian Brook Crayfish, the Robust Crayfish, the Northern Clearwater Crayfish, the Papershell Crayfish, the Obscure Crayfish and the Rusty Crayfish.

LIFE HISTORY: In Ontario, Quebec, Saskatchewan and Alberta, the Virile Crayfish mates from July to September and perhaps again in the spring. Eggs are laid from late May to early June and hatch in July *(Sawchyn, 1986; Talbot, 1985; Weagle and Ozborne, 1972)*. Young moult 5 times in the first summer and 3-4 times in the second. Crayfish mature within the first or second year. Mature males moult from Form I to Form II in mid-June and back again to Form I in early August. Mature females moult once only in July when their young leave. The average life span is 3 years and maximum size is 55 mm CPL at about 3-4 years of age *(Sawchyn, 1986; Talbot, 1985; Weagle and Ozborne, 1972)*.

CONSERVATION STATUS: This species is widespread and common especially in the western parts of Canada. In Alberta, where the species apparently occurred naturally in the Beaver River drainage, it has been introduced by baitfishermen into water bodies up to 400 km (249 mi.) from the nearest possible source *(Hanson et al.,1990)* and crayfish have been reported recently from the North Saskatchewan and Battle Rivers *(Saffran, pers. comm.)*.

On the other hand, the Virile Crayfish is locally threatened in many watersheds in eastern Canada. It is presently being displaced by the introduced Rusty Crayfish in many areas of southern and northern Ontario *(Berrill, 1978; Momot, 1997)*. Local declines may also be due to air and water pollution and associated chemical changes in watersheds. A study of crayfishes in lakes of the Canadian Shield in Ontario found a decline in the Virile Crayfish as well as other native species. It was suggested that these declines may be linked to low pH and high aluminum concentrations *(David et al., 1994)*. Acidification of lakes has been shown to cause reductions in the fecundity of this species and it was concluded that reproductive failure could cause the disappearance of crayfish populations long before water becomes acidic enough to cause direct mortality. A pH of more than 5.8 is apparently needed for successful egg attachment *(France, 1987a)*. Acidification also results in reduced carapace rigidity which makes crayfishes more vulnerable to predation and mechanical stress.

The Virile Crayfish has been shown to be a good indicator of mercury contamination in water bodies in Ontario and Manitoba *(Vermeer, 1972)*. Studies in the Sudbury area where emissions of heavy metals remain high showed that, although metals were accumulated, the species appeared to be tolerant to copper, cadmium and nickel *(Bagatto and Alikhan, 1987)*. A study of the potential for commercial exploitation in various Saskatchewan rivers and lakes showed that the levels of heavy metals (mercury, arsenic, lead, copper etc.) and organic compounds (e.g. PCB, DDT, dieldrin) were at least an order of magnitude lower than levels accepted for human consumption *(Sawchyn, 1986)*.

This species has been the subject of numerous studies in Canada and, as a result, a good database dealing with its biology, ecology and physiology exists in the literature. The main gaps in knowledge remain in the documentation of its distribution, particularly in the most northern regions of its distribution and its interaction with introduced or expanding species. Despite local extinctions, the Virile Crayfish is still common and has a very extensive distribution (with many "safe" populations outside of the range of the introduced species) and must therefore be considered to have a "Currently Stable" status in Canada.

COMMERCIAL EXPLOITATION: The Virile Crayfish has been harvested commercially from wild populations and has been used in several pilot projects that evaluated the economic potential of northern crayfish species. Studies of native U.S. midwestern crayfish species suggests that their reproductive characteristics and production are offset seasonally from crayfishes in the south and thus midwestern farmers may have an opportunity to fill a market niche with a native species at a time of year when there is no competition for fresh product *(Brown, et al., 1990)*.

Laboratory studies using Virile Crayfish indicated significant potential for pond production of native species for the tail-meat market. Production levels ranged from 323-807 kg/ha when fed on agricultural forage *(Brown et al., 1990)*, which compared favorably with average production levels in the south of 545-691 kg/ha *(Roberts and Harper, 1988)*. The evaluation of soft-shell production showed that while the total number of crayfish that moulted over a 30-day experimental period was higher at 20˚C (68˚F), a higher percentage moulted in a shorter period of time at 30˚C (86˚F) than at lower temperatures *(Brown, 1993)*. Regardless of temperature, there was a two-phase response of moulting activity that became more pronounced as temperature increased for 20-30˚C (68-86˚F). Generally, a large number of crayfish moulted within the first 5-10 days (up to 64% of the populations reared at 30˚C), followed by a quiescent period, then another period of moulting *(Brown, 1993)*. *Huner (1993)*, in his summary of aquaculture in Orconectes, states that growth in Virile Crayfish has been shown to be dependent on food availability and population density. Uncontrolled reproduction in culture ponds leads to higher population densities, reduced growth rates and smaller maturation size.

Crayfish suitable for commercial harvest can be generally produced in 12-14 months but, if initial stocking densities are controlled, harvestable animals can be produced within one summer. Rotation of ponds and restocking are recommended to reduce overpopulations and stunting of crayfish populations.

Momot (1988, 1991) points out that crayfishes are an abundant and largely unexploited food resource in northcentral North America. In his studies of the potential for exploitation of crayfishes in temperate and northern systems, he notes that crayfish populations in southern Ontario and Canada in general are resilient, self-regulating and capable of producing sustained yields. He further suggests that as long as the habitat stays intact, harvesting 50-60% of the adult population is possible with little danger of growth or recruitment overfishing, and that the most desirable tactic for a trap fishery may be to harvest without size and sex restriction, provided that females with eggs are not taken *(Momot, 1991)*. He estimates, however, that in northern populations of the Virile Crayfish, only about 10% of the catch is of marketable size, resulting in yields of approximately 2.4-14.3 kg/ha *(Momot, 1988)*.

A study of the potential for development of a crayfish industry in Saskatchewan (Canada) concluded that although there were promising populations of the Virile Crayfish (in terms of size range and density) in many lakes in the southern part of the province, none of the sites provided significant numbers of crayfishes large enough for the minimum size requirements for export to the European market *(Sawchyn, 1986)*. Some of the populations were found to have substantial numbers of crayfish comparable to Louisiana-grown crayfishes (7.5-9.0 cm/2.93-3.51 in. total body length). As crayfishes did not respond well to any variety of trapping methods, harvesting was accomplished by hand collecting. Crayfishes from the samples were well within the acceptable limits with respect to pesticide residues and metals *(Sawchyn, 1986)*.

Preparation of crayfishes using Scandinavian techniques of boiling in brine and dill broth apparently produced a tasty attractive product that can be preserved and stored by vacuum packing and deep-freezing. However, test marketing of the Saskatchewan wild harvested Virile Crayfish in Europe revealed that they are not acceptable because of their smaller size. It was deemed possible that these crayfishes could be sold locally (at about $11.00/kg, providing a return of about $5-6/kg) but, in order to develop a local market, more efficient harvesting methods would have to be developed and long term evaluations of intensive harvesting on wild populations would have to be performed *(Sawchyn, 1986)*.

Momot (1988) suggested that more efficient methods of harvesting and processing need to be developed in order to make wild fisheries sustainable. Processing crayfishes for tail meat only would enable the use of smaller sizes of crayfishes that are abundant in wild populations (up to 50% of the total) and thus increase yields and profitability. He proposed that fishing just 10 ha of a watershed could produce a gross income of up to $5,000 per day (100 traps/ha = 600kg at $2/kg). Virile Crayfish have also been harvested commercially in Quebec from the St. Lawrence river where the two species are locally abundant. The Virile Crayfish makes up a variable portion (6-86%) of the commercial harvest in Lac Saint-Pierre and the St. Lawrence River *(Baribeau et al., 1982, 1983; Portlance, 1987)* and the effect of this harvest on the interaction between these two species is unknown.

-11-

An Overview of Crayfishes

TAXONOMY AND DISTRIBUTION

OVERVIEW

Crayfishes are members of the Phylum Arthropoda (invertebrate animals with segmented legs) and are distantly related to insects and spiders exhibiting morphological features similar to other crustacean relatives such as marine lobsters, crabs and shrimps (*Crocker and Barr, 1968*). To date approximately 500 species of freshwater crayfishes belonging to three families have been identified globally. The family Parastacidae (in Australia, South America, Madagascar and New Zealand), the family Astacidae (in Europe, Asia and western North America) and the family Cambaridae (in North and Central America as well as East Asia) (*Hamr, 1998*).

NORTH AMERICAN CRAYFISHES

North America is home for two families of freshwater crayfishes which have historically occupied non-overlapping ranges. The first family of North American crayfishes are the Astacidae which are restricted in distribution to the west coast of the United States and Canada and are represented by a few species of the genus Pacifastacus (The Signal Crayfishes) (*Huner, 1995*). The other family of crayfishes to inhabit the North American continent are the Cambaridae. The Cambaridae family of crayfishes occur in some Hudson Bay watersheds, the Atlantic, and gulf drainages from southern Canada to Honduras and certain Pacific slope basins in both Mexico and Cuba (*Hobbs III, 2001*).

Within these two families combined (Astacidae and Cambaridae) 342 species and sub-species (introductions ignored) occur which are restricted to North America (north of Mexico). This rich fauna is assigned to a total of 12 genera. The southeastern United States harbors the highest number of crayfish species (*Taylor et al., 1996*) with the number of crayfish species progressively declining with increasing northerly latitudes (*France, 1992; Hobbs III, 2001*) (Figure 10).

CANADIAN CRAYFISHES

Canada is represented by two families (Family: Astacidae and Family: Cambaridae) of North American distribution (Figure 10). Of these two families, the Cambaridae with three Canadian genera and 10 species is widely distributed throughout Canada east of the Rocky Mountains with crayfishes from this family being recorded in Alberta, Saskatchewan, Manitoba, Ontario, Quebec and New Brunswick. These Canadian populations of crayfishes are unique in that they represent the northern-most points of their distribution and thus often exhibit different life history and ecology from their southern U.S. counterparts (*Hamr and Berrill, 1985; Crocker and Barr, 1968; Hamr, 1998*).

ONTARIO CRAYFISHES

Of all the Canadian provinces, Ontario has the richest crayfish fauna with three genera within the family Cambaridae. These genera are *Cambarus* (with three species), *Fallicambarus* (with one species) and *Orconectes* (with five species) which together comprise a total of nine confirmed species in Ontario – two of which have been introduced from the United States (*Crocker and Barr, 1968; Hamr, 1998*) (Figure 10).

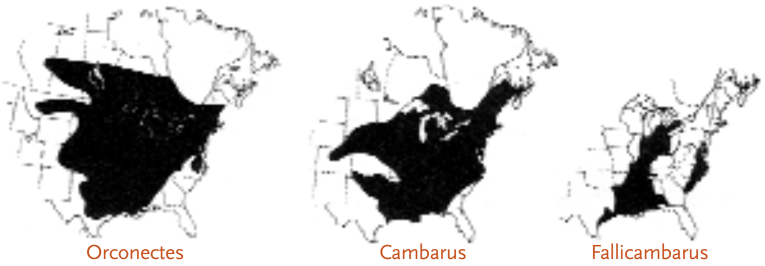


FIGURE 10: *Distribution of the Cambarus, Fallicambarus and Orconectes genera crayfishes (Family: Cambaridae) in North America (modified from Hobbs, Jr, 1988 in Hamr, 1998)*

ANATOMY AND MORPHOLOGY

GENERAL BODY PLAN

The body plan of all crustaceans is divided into three regions: the **head**, **thorax** and **abdomen**. When looking down upon a crayfish (called dorsal view) two distinct regions can be observed as a result of considerable fusion of the head and thorax. The first region is towards the anterior (the head end of the crayfish) un-segmented portion. The second region is the posterior region (towards the tail end of the crayfish) that ends in a tail fan. The anterior (head) region of the crayfish is covered by a rigid relatively smooth exoskeleton and is known as the **cephalothorax** (cephalon – head; thorax – chest) or **carapace**. The rest of the body is called the **abdomen**. The entire animal is encased in a hard chitinous cuticle called the **exoskeleton** (Figure 11).

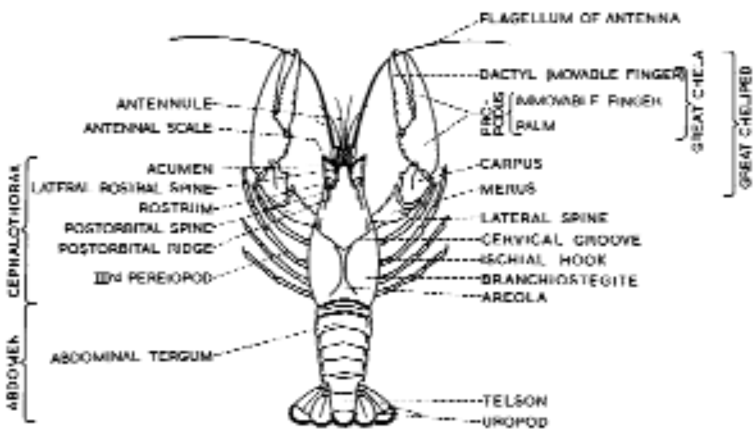


FIGURE 11: *Dorsal view of a male specimen of the widespread Ontario crayfish (Orconectes virilis) the Virile Crayfish, illustrating the morphological features of main importance (with permission from the Royal Ontario Museum – C.N. Storwick – Artist)*

THE CEPHALOTHORAX

Note that that the dorsal side of the crayfish cephalothorax does not have any segmentation. However, the ventral (underside) of the cephalothorax has distinct segmentation. The cephalothorax length (CPL) or carapace length (CL) is often used as a standard to measure the size of a crayfish. When looking at the anterior of the carapace in dorsal view and following it forward it can be noted that the carapace projects forward as a flat "horn" over the base of the eyes. This tapering projection is called the **rostrum**, the structure of which can be a useful aid when identifying the crayfishes of Ontario. At the tip of the rostrum is a sharply pointed projection called the **acumen**. At the base of the rostrum on each side is the socket for the **stalked eye**.

Still looking at the crayfish in dorsal view, a transverse fissure called the **cervical groove** marks the limit of the head region. It curves forward on both sides of the carapace to meet the anterior margin. The lateral extensions (surfaces facing away both left and right from the midline of the crayfishes body) posterior and ventral to the cervical groove are called the **branchiostegites**. The branchiostegites are not attached to the crayfish body along the ventral (same side the legs are on the bottom) or posterior (toward the tail). This allows the **gill (branchial) chambers** housed behind the branchiostegites to be open from below and behind in order to access oxygen from both water and air. It is within these chambers that the crayfish **gills** or **branchiae** are housed. The outline of the branchial chambers on either dorsal side of the crayfish body is represented as a concave median (a surface facing the midline of a crayfishes body) sided area termed the **areola**. This is the hourglass-shaped line found on the back of a crayfish between the head and the tail and can sometimes be used in the identification of Ontario crayfishes. The carapace or cephalothorax can in some instances exhibit various spines and tubercles. The most conspicuous of these are the **lateral rostral spines** at the base of the acumen and the **lateral spine** halfway along the cervical groove below the eye (Figure 11).

THE ABDOMEN

Looking down upon (dorsal view) the abdomen of a crayfish segmentation is obvious. It can be noted that in total there are six distinct, moveable segments and a terminal flat plate which is called the **telson**. The telson is the last center segment of the tail and is flanked on either side by two pairs of segments that form a fan-like structure called the **uropod**. This structure bears the **anus** on the bottom (ventral) side. As a result of this segmentation the abdomen is flexible and is used in locomotion. On the bottom surface of the female crayfish abdomen are five pairs of visible appendages called **pleopods**. The back and forth fanning of the ventral side of the abdomen using these appendages functions to aid in the circulation of water around the crayfish body (Figure 11).

THE HEAD

The head apparatus of crayfish perform a variety of functions but consists primarily of sensory apparatus which gathers information about the crayfish's environment and is used to handle and process food items. Beginning at the anterior end of the crayfish, the pre-segmental region bears the **compound eyes**.

Compound eyes are common to many arthropods – each resides at the end of a short stalk on either side of the rostrum that allow the eyes to point in different directions. A more obvious and familiar head appendage are the **antennules** each having two long whip-like branches. In addition, the **antennae** can also be observed and are thought to function in the detection of chemicals in the water. Another group of appendages are grouped around behind the mouth involves the handling of food. This includes the grasping and tearing of food and moving the pieces of food to the mouth (Figure 11).

THE THORAX

The thoracic appendages of crayfishes are used for eating and walking. In total there are eight pairs of thoracic appendages. The first three pairs are referred to as the first, second and third **maxillipeds**. These three appendages aid the three pairs of head appendages in the processing and ingesting food. The next five pairs of thoracic appendages are called the **pereiopods**. The first pair contains the familiar massive **chelae** or claws and are greatly enlarged and strongly muscled. Their large size relative to the crayfish body makes these large claws unsuitable for walking. However, these massive claws or pincers are put to use in the search and seizure of food, burrowing, and self-defense from predators such as fishes and other crayfishes. The remaining four pairs of walking legs or pereiopods are used for walking and grasping. Each pereiopod is composed of seven elongate articulated segments: the **coxa**, **basis**, **ischium**, **merus**, **carpus**, **propodus** and **dactyl**. The first three pairs of pereiopods have the **dactyl** articulated on the side of the **propodus** so that it apposes the projecting distal end of the latter. The result is the grasping claw or **chela** (singular). A pereiopod bearing a grasping claw it is referred to as **cheliped** (Figure 11).

MALE REPRODUCTIVE ORGANS

Male crayfishes differ from females in that the first two pairs of abdominal pleopods are modified to form sexual organs which function in the transfer of sperm to the **seminal receptacle** or **annulus ventralis** of the female. The first pair of modified male crayfish abdominal pleopods are called the **copulatory stylets**. The copulatory stylets are held close to the body and point towards the head. In sexually mature male crayfishes these sexual organs are strongly calcified being thin, hard and amber in appearance. The copulatory stylets of sexually mature male crayfishes are the single most important character used to differentiate crayfish species in eastern and central North America (Figure 14). However, as stated, only sexually mature males have the diagnostic features helpful in identifying different species of crayfishes. In sexually immature males the copulatory stylets are not calcified, are often white, and are much smaller in size, being more difficult to observe.

FEMALE REPRODUCTIVE ORGANS

On the ventral side of the thorax of female crayfishes is a reproductive organ known as the **seminal receptacle** or **annulus ventralis** which is located between the bases of the fourth and fifth pairs of perieopods. It is a flat, thickened plate of cuticle and contains a short blind ending canal which penetrates to the centre of the seminal receptacle. The seminal receptacle receives sperm from sexually mature males and holds it in the form of a sperm plug until the time of fertilization. It should be noted that the structure of the seminal receptacle is a very useful diagnostic feature that can be used for identifying mature female Ontario crayfishes (Figure 15).

* For greater detail please see *Crocker and Barr, 1968*.

GENERAL PHYSIOLOGY

CRAYFISH MOVEMENT

Crayfishes move either by walking or by swimming and darting which involves a rapid backward "tail-flip". Crayfishes can walk either forward or backward by using their walking legs which are spread out on either side on the underside of the individual. In terms of morphology, *Alexander (1971)* hypothesized that the sprawling posture of crayfish walking legs was an adaptation to withstand over-turning in strong lateral currents. In strong currents the large claws of crayfishes are positioned forward to evenly balance the weight of the abdomen. They may also be used to secure a position in running water currents by positioning them in front of the body (*Maude and Williams, 1983*). In doing so, water is deflected over the top and along the sides of the crayfish thereby preventing it from being swept away.

CRAYFISH RESPIRATION

Crayfishes have come to occupy nearly every type of aquatic habitat as they are highly tolerant and highly adaptable animals, particularly in regard to respiration (*Hobbs III, 2001*). For example, *O. immunis* (Papershell Crayfish) is found in stagnant waters associated with roadside ditches, shallow ponds and pools. This species has the ability to live and flourish under severe environmental conditions such as low dissolved oxygen (*Hobbs III, 2001*). Unlike respiration by certain aquatic amphibians, such as frogs, in which gas exchange occurs through the thin epidermal layer of the animal, the dissolved oxygen required for respiration by crayfishes cannot pass through the thick crayfish exoskeleton. Subsequently, gas exchange by crayfishes involves the uptake of dissolved oxygen by the gills.

Crayfish gills are situated along either side of the thorax in the gill chamber and are exposed to the external environment along the bottom of the chamber thereby allowing them to take in oxygen from the external environment. The gills of crayfishes are highly efficient and are capable of extracting as much as 70% of the oxygen within the respiratory current (*Holdich and Lowery, 1988*). Crayfishes living in permanent aquatic environments are also capable of living out of water for extended periods as long as the air coming into the gill chambers is humid enough that they can extract enough oxygen to survive. Some burrowing species of crayfish (e.g. *C. diogenes* – Devil Crawfish and *F. fodiens* – Chimney Crayfish in Ontario) can survive for several months in moist burrows with low oxygen and, if oxygen levels get too low, they can emerge to flush their gills with fresh oxygen from the air (*Holdich and Reeve, 1988*).

CRAYFISH FOOD AND FEEDING

OVERVIEW

As a result of their ability to consume a variety of food items, crayfishes can often maintain large population densities within aquatic ecosystems despite unpredictable periodic fluctuations in available food resources (*Hobbs III, 2001*). Having non-specialized feeding habits, crayfishes are fully capable of switching between trophic foraging positions. For example, crayfishes are capable of switching roles from herbivores/carnivores to scavengers/detrivores in response to food availability (*Hobbs III, 2001*). Having the ability to feed directly on animal and plant material associated with both aquatic and terrestrial ecosystems crayfishes play an important role in the cycling and recycling of nutrients in ponds, rivers, lakes and streams (*Hobbs III, 2001*). The wide-ranging feeding habits of crayfishes are advantageous to crayfish culturists, aiding in the establishment of successful low maintenance crayfish aquacultural enterprises (*Goddard, 1988; Huner, 1990*).

FORAGING

Crayfishes are opportunistic foragers and can consume as much as 16% of their body weight daily (*Momot, 1995*). Crayfishes also have preferences for certain kinds of foods depending upon age, season and physiological condition (*Goddard, 1988*). In general, adult crayfishes feed mostly on vegetation and detritus, whereas juvenile crayfishes feed primarily animal matter. These conclusions have been substantiated through the careful examination of stomach contents of crayfishes (*Goddard, 1988; Huner, 1990; Momot, 1995*). Although crayfishes forage nearly continuously, foraging peaks occur shortly after sunset and throughout the night presumably in response to daytime predation by fishes. (*Hobbs III, 2001*).

DETRITAL FEEDING

Detritus is generally defined as rotting vegetation. Although crayfishes are polytrophic, the majority of their diets appears to consist of detritus. Detritus is considered to be the main source of food for pond-cultured species (e.g. *Orconectes immunis* – Papershell Crayfish). However, associated with detritus are smaller organisms such as fungi, bacteria and protozoa (*Momot, 1995*). These microorganisms are also thought to be important food sources for crayfishes in both managed crayfish ponds and their natural environment (*Goddard, 1988*). Annual grasses, including cultivated plants such as rice and millet are often intentionally grown in commercial crayfish ponds to provide detritus, a food base for crayfish production (*Huner, 1990*).

HERBIVORY

Living aquatic plants (e.g. rice and millet) are also thought to comprise a significant proportion of the food of freshwater crayfishes (*Goddard, 1988*). Crayfishes can significantly reduce both the numbers of aquatic plant species and the amount of aquatic plant material present through selective grazing (*Lorman and Maguson, 1978; Lodge and Lorman, 1987; Feminella and Resh, 1989; Lodge, 1991; Creed 1994; Lodge et al., 1994; Momot, 1995*). Crayfishes as herbivores have been observed to control and even eliminate plants from aquatic ecosytems. However, the apparent nutritional importance of plants has only been assumed given the observation that submerged macrophytes are often greatly reduced or even eliminated from water bodies where crayfish populations achieve dense population levels (*Lodge and Lorman, 1987; Chambers et al., 1990; Momot, 1995*).

Doubts about the assumed nutritional role of aquatic plants arise from observations that crayfishes often uproot or snip off submerged macrophytes at their base when actively foraging. As a result of the presence of crayfishes in the shallow shore zone of lakes, the snipping of stems near the bottom has been observed to destroy ecologically important (e.g. fish habitat) aquatic plant beds although the crayfishes themselves actually ingest very little of the plant *(Hobbs III, 2001*). Observations on crayfishes in captivity have shown that crayfishes will also consume a wide variety of "plant-like" material including lettuce leaves, carrots, potatoes, spinach, bananas, tomatoes and tree leaves, albeit crayfishes fed such diets grow more slowly than those fed animal or other high value protein (*Goddard, 1988; Jones and Momot, 1993; Brown et al., 1992; Momot 1995*). This may be of some interest to crayfish culturists who wish to grow and harvest smaller "stunted" crayfishes which are preferred by anglers.

CARNIVORY

Crayfishes as consumers of animal matter prey upon a variety of organisms including clams and mussels (including zebra mussels), thin-shelled snails, aquatic insects, aquatic worms, tiny crustaceans and amphibian tadpoles (*Goddard, 1988; Huner, 1990*). Additionally, crayfishes are also thought to compete for food with other aquatic vertebrate predators such as fishes. Crayfishes are mainly opportunistic scavengers and most crayfishes will preferentially select living and dead animal matter over fresh or decaying vegetative material (*Crocker and Barr, 1968; Momot, 1995*). Juvenile crayfishes will nearly always preferentially select a high protein diet (*Ackerfores et al., 1992; Momot, 1995*). Cannibalism is also an important aspect of the feeding activity in crayfish populations and becomes particularly important in crayfish populations with a large number of aggressive males.

FILTER-FEEDING

There is also evidence that crayfishes are able to filter-feed upon suspended organic material such as algae. Such material is thought to be ingested through the filtration of water by the crayfish feeding apparatus. Juvenile crayfishes have even been observed to methodically stir up and filter-feed upon suspended soft substrate material (*Momot, 1995*). Filter-feeding may be an especially important food source for refuge seeking juveniles and adult crayfishes during the moulting period when the old exoskeleton is shed and the hardening of the new exoskeleton begins.

CHEMORECEPTION

Little effort has been made to examine the role or influence of chemical stimuli on the foraging behaviour of crayfishes. It has been suggested that chemosensory induced foraging in crayfishes may be related primarily to obtaining food from nearby rather than distant food sources (*Hobbs III, 2001*). The detection of food is thought to be a function of specialized hairs located on the antennules (Figure 11) and mouthparts of crayfishes (*Holdich and Reeve, 1988*). Information from these chemoreceptors is evaluated by the crayfish and the direction of food determined. Chemoreceptors of this nature are thought common to all crayfishes (*Holdich and Reeve, 1988*). It is now thought that amino acids are responsible for the chemical feeding cues of freshwater crayfishes in aquatic ecosystems (*Hobbs III, 2001*).

BEHAVIOURAL ECOLOGY

In Ontario, crayfishes generally mate from spring to early summer or in autumn depending on species and water temperature (*Hamr, 1998*).

MATING SEASONS

Orconectes

Ontario crayfish species belonging to the genus *Orconectes* which include *O. virilis* (Virile Crayfish), *O. rusticus* (Rusty Crayfish), *O. immunis* (Papershell Crayfish), *O. obscurus* (Obscure Crayfish) and *O. propinquus* (Northern Clearwater Crayfish) all mate around the same time and have relatively comparable life cycles (*Berrill, 1978*). Mature individuals generally mate in spring and/or autumn. Such mating results in the fertilization of eggs which mature females extrude in spring and carry for a few weeks until they hatch. The only divergence from this scheme among the five *Orconectes* species in Ontario is that some *O. immunis* (Papershell Crayfish) females may extrude their eggs in late autumn and carry them over winter (*Berrill, 1978*). Given the life cycle synchrony among *Orconectes* species in Ontario, any variation in the timing of life cycle events in populations that are widely separated geographically are thought to be primarily as a result of differences in ambient water temperature which is linked to increasing or decreasing latitude and altitude (*Berrill, 1978*).

Cambarus (including Fallicambarus)

Studies on seasonal mating habits of the more specialized *Cambarus* (including *Fallicambarus*) species in Ontario are few. Given the notable lack of temporal mating synchrony, mating behaviour in crayfishes of the genera *Cambarus* (including *Fallicambarus*) is complex. Unlike the *Orconectes* genera in Ontario, species of the *Cambarus* genera (and *Fallicambarus* genera) appear to lack any obvious synchrony (*Hamr and Berrill, 1985*). However, *Cambarus* life cycles do appear to be related to water temperature and light which influences both the moulting and reproductive cycles (*Berrill, 1978; Hamr and Berrill, 1985*).

MATING BEHAVIOUR

During the mating season the sperm ducts of sexually mature breeding male crayfishes are full (*Crocker and Barr, 1968*). Sexually mature males actively seek out females although attempted male-to-male copulations are often observed and not uncommon. If a male has been accidentally seized it will fight back until the aggressor moves on (*Crocker and Barr, 1968*). If a receptive female has been seized, she enters a non-resistant "trance-like" state. The male will then place the female crayfish onto her back and then seize her large claws and walking legs with his own large claws. The male crayfish then inserts his copulatory stylets in the blind ending canal of the females seminal receptacle. At this time, the process of sperm transfer from the male to the female begins. The duration of this event may range from a few minutes to several hours (*Crocker and Barr, 1968*). Once viable sperm has been transferred to the female, it is stored in the female's seminal receptacle.

EGG-LAYING

Upon successfully mating with a male, a female crayfish will carry the male's sperm until the time of egg-laying. The process of egg extrusion and laying is called oviposition. It is thought that an interaction between water temperature and light controls the onset of oviposition (*Berrill and Arsenault, 1982*). Just before oviposition female crayfishes become highly sensitive. They are so sensitive at this time that, if disturbed, they may actually die (*Crocker and Barr, 1968*). Also during this time females become reclusive and seek out hiding places. Immediately prior to egg extrusion the female turns onto her back and bends the abdomen forward. At this time, a substance called "glair" is released and begins to fill the cavity formed by the folded abdomen (*Crocker and Barr, 1968*). Sperm stored in the females seminal receptacle are then released into the glair. It is at this point that the eggs are extruded from the female and pass over the glair that is now full of recently released sperm and fertilization occurs (*Crocker and Barr, 1968*). Eventually, the eggs are coated with a thin layer of glair that hardens. The hardening of glair acts as an adhesive attaching the eggs to the females pleopods. As the pleopods are fanned, each egg pulls slightly away from its pleopod and develops upon a short stalk of hardened glair. The female eventually turns back over and with a full load of eggs fixed to her pleopods, she is said to be "in berry" (*Crocker and Barr, 1968*).

EGG INCUBATION AND HATCHING

Once oviposition and fertilization are complete, recently laid eggs will incubate from 2-20 weeks depending upon the time of year and water temperature. During this time developing eggs are fanned and subsequently aerated by the female using her pleopods (*Crocker and Barr, 1968*). The eggs eventually hatch and the newly hatched crayfishes are the first of three readily distinguishable juvenile stages during which the juveniles are associated with the female parent (*Crocker and Barr, 1968*).

The first stage young remain attached to the remains of the egg on the bottom side of adult female for 2-7 days. The second stage juveniles are no longer attached to the remains of the egg but they remain attached to the adult female using their large claws. These juveniles look more like adults in appearance. They usually remain attached to the female throughout the 4-12 day duration of this developmental stage (*Crocker and Barr, 1968*). Crayfishes in the third juvenile stage have almost all of the morphological features of adult crayfishes although such juveniles may only be 10 mm total length (TL) (*Crocker and Barr, 1968*). Third stage juvenile crayfishes cling to the pleopods of the female with their chelae and pereiopods but often leave intermittently to forage. If these juveniles are alarmed in any way they immediately return to the protection of the female (*Crocker and Barr, 1968*). Overall, hatchlings may remain adhered to the female for as long as 2 months during which time the female provides constant protection and care. After this period the hatchlings become fully independent.

Subsequent juveniles are entirely free-living and in most species may be captured throughout the summer in open water. Even the juveniles of some burrowing species (e.g. *Cambarus diogenes* – Devil Crawfish) are found in surface waters during the early part of the growing season (*Crocker and Barr, 1968*). Independent juveniles avoid both each other and the female. Generally, newly hatched juveniles undergo at least 11 molts before reaching maturity. Under ideal conditions this can be completed in one growing season (e.g. 3-6 months) regardless of altitude, but individuals such as those found in Ontario often do not mature until there is a second growing season.

MOULTING

Crayfishes can only increase in size by periodically shedding their exoskeleton during the process of moulting (*Lowery, 1988*). Rates of growth in crayfishes depend upon the number of moult cycles that a crayfish can complete in a year. As such, there has been considerable investigation of the factors that control the moult cycle. Crayfishes grow in a series of abrupt steps rather than in an uninterrupted progression (*Crocker and Barr, 1968*). Subsequently, the moulting process involves far more than just periods of continuous growth facilitated by the simple splitting of the exoskeleton (*Hobbs III, 2001*). The moulting cycle dominates the life of crayfishes and can impose constraints on management practices involved in their culture (*Lowery, 1988*).

Moulting also allows for seasonal changes in morphometric form and sexual competence (sexually mature v.s. sexually immature) in all male crayfishes of the Cambaridae family (including all of Ontario's nine crayfish species). Such an event, although a critical process for growth, is a physiologically demanding and ecologically vulnerable period in the lives of crayfishes (*Brewis and Bowler 1983; Mundahl and Benton 1990; Hobbs, 1991, Hill et al., 1993; Lodge and Hill, 1994; Hobbs III, 2001*). The moult cycle is generally divided into five stages: (i) soft, (ii) post-moult, (iii) intermoult, (iv) pre-moult and (v) the moult itself (*Waddy and Aiken, 1987; Huner, 1994*). All of these phases are controlled by hormones (*Hobbs III, 2001*). The intermoult stage is the main functional phase in the life of crayfishes. It is at this time that crayfishes feed, reproduce and accumulate reserves (e.g. calcium) for the next period of growth that starts with preparation for moulting (*Lowery, 1988*).

With the approaching moult, the old crayfish exoskeleton demineralizes and becomes progressively thinner and more brittle as calcium is reabsorbed (*Huner, 1994*). This pre-moult stage is of particular interest to crayfish culturists from the standpoint of soft-shelled crayfish production. Beneath the old exoskeleton an unmineralized exoskeleton forms and, midway through the pre-moult stage, it separates from the old exoskeleton (*Huner, 1994*). At the very end of the pre-moult stage, the old cuticle splits and the crayfish emerges from the old exoskeleton. It is at this time that all crayfishes become extremely vulnerable to both cannibalism and attack by fish predators (*Lodge and Hill, 1994*). It is also during this short post-moult period that all tissues begin to rapidly grow. In order to mineralize and harden the new exoskeleton as quickly as possible, crayfishes can in part utilize calcium by eating the remains of the old exoskeleton and from reabsorbed calcium obtained from calcareous stomach stones called gastroliths. Additional sources of calcium must come from food and water (*Huner et al., 1978; Huner, 1994; Hobbs III, 2001*).

MOULT HORMONES

The moulting process in crayfishes is governed by hormones. Moult inhibiting hormone (MIH) is produced in the eyestalks by what are known as the "x-organs". When required, these "x-organs" produce MIH which inhibits and subsequently prevents the moulting process from occurring. Conversely, there are also exists a pair of glands located beneath the epidermis of the carapace called the "y-organs". These "y-organs" produce and secrete a hormone, which stimulates moulting (*Hobbs III, 2001*) and is called Moult Stimulating Hormone or MSH. When there are high levels of MIH, the crayfish moult is inhibited. When there are high levels of MSH, moulting in crayfish is activated (*Huner, 1994*). Thus, both the promotion and inhibition of the moulting process in crayfishes is controlled by the production and release of these hormones.

Under certain conditions (e.g. light, temperature, loss of limbs, eye-stalk removal) moult-inhibiting hormones (MIH) are not released and the "y-organ", no longer suppressed by MIH secretes moult-stimulating hormone (MSH) (*Stoffell and Hubschman, 1974; Hobbs III, 2001*). Crayfish culturists have known for some time that bilateral eyestalk removal (ablation) stimulates the production of MSH and the moulting process in freshwater crayfishes (*Aiken and Waddy, 1987*). Bilateral eyestalk ablation is thought to be one of the most effective ways of initiating the moulting process for the production of soft-shell crayfish. Injection of purified moult stimulating hormones will also induce moulting but the moulting is normally incomplete unless the hormone is injected in relatively small doses over time (*Huner, 1994*). Such a procedure has obvious shortcomings. As of yet, no one has developed an effective yet practical procedure to stimulate the moulting process through the injection of hormone into or feeding hormones to crayfishes. However, eye-stalk ablation research continues and it shows promise (*Huner, 1994*).

SEXUAL MATURITY

All of Ontario's nine crayfish species belong to the family Cambaridae. In this family the exoskeleton the male crayfish occurs in two distinct morphological forms. These distinct forms are a result of life cycles that alternate between a sexually mature and sexually immature condition (*Huner, 1990*). Outside of the breeding season, males moult out of the sexually active phase (Form I) into a sexually inactive phase (Form II) (*Berrill and Arsenualt, 1984*). This alternation of morphological form is called cyclic dimorphism and occurs to a greater or lesser extent in all of the male crayfishes of Ontario. The transition from the sexually mature Form I to the sexually immature Form II is the result of the moulting process. A juvenile hormone, called JH, has been identified in crayfishes and is implicated in the transition between these two sexual forms (*Laufer et al., 1986; Huner, 1994*).

Many of the structural features of the exoskeleton of male crayfishes are affected by the moult. For example, the Form I condition is characterized by increased length and sharpness of all spines and sclerotized structures. In addition, Form I males attain significantly heavier claws. Also, the central projection of the male copulatory stylet becomes hard and is amber to brown in colour. The sexually immature Form II condition is found between periods of sexual activity and closely resembles the juvenile form (*Crocker and Barr, 1968; Huner, 1990; 1994*). Unlike Form I males, sexually immature Form II male crayfishes have much smaller chelae and non-functioning copulatory stylets. When crayfishes are in the Form I condition, the copulatory stylets of males are the most reliable method of identifying and separating Ontario's nine species as the shape of the male copulatory stylets are species specific (Figure 14). In addition, the seminal receptacle (annulus ventralis) of sexually mature female crayfishes are also species specific. Sexual maturity in female crayfish can also be determined by the presence of glair glands visible as white areas on the uropods of females and/or attached eggs on the pleopods (*Hamr, 1998*). The species-specific differences in the male copulatory stylets (Figure 14) and the morphology of female seminal receptacle (Figure 15), for the most part, prevents hybridization between most species.

FECUNDITY

Upon extrusion, the eggs of sexually mature adult female crayfishes can be counted. The number of eggs carried per female per breeding season is defined as fecundity (*Corey, 1987b*). Thus by counting pleopodal eggs it is possible to follow the progression of a batch of eggs laid by a given individual through until hatching (*Lowery, 1988*). Data of this sort allows for a rough determination of the productivity of individual crayfishes (*Lowery, 1988*). *Corey (1987a, 1997b)* showed that, in general, a positive relationship exists among the number of eggs carried by a female and the size of the female. Roughly, the fecundity of female crayfishes appears to be related to the area capacity for egg attachment. However, it was noted that the number of eggs carried and the size of the female can vary considerably both within and between species. This variation may simply represent differences between individuals such as the greater fecundity of larger animals or it may reflect mechanisms which are controlling the overall fecundity of the population as a means of affecting the structure of the population and the pattern of recruitment of juveniles (*Corey, 1987a, 1997b; Lowery, 1988*).

CRAYFISH POPULATION REGULATION

OVERVIEW

Four major features affect the size and growth of any population of living organisms. They are birth, death, arrival and departure. These four population features are regulated by a number of abiotic (non-living) and biotic (living) factors (*Hobbs III, 2001*). Although each of these factors alone can play a role in affecting community composition, population size and growth of populations, any combination of abiotic (e.g. temperature and dissolved oxygen) and biotic factors (e.g. foraging activity and predation) can also interact strongly with each other (*Lodge and Hill, 1994; Hobbs III, 2001*).

ABIOTIC FACTORS

Temperature

Of all of the wide-ranging abiotic environmental factors influencing the regulation of crayfish populations, temperature is thought to be the most important. The growth rate of crayfishes, like that of other cold-blooded animals, is greatly affected by temperature. It is well known that crayfish productivity decreases with cooler water temperatures associated with increasing latitudes or altitudes (*Momot, 1991*). Water temperature is thought to explain the observed variation in growth rate in northern populations of many cool-water crayfish species as compared to the same species living in warmer more southerly distributions. Higher water temperatures promote crayfish growth by increasing the moult increment. However, there is a tradeoff as the apparent advantage of rapid growth in warmer environments is gained at the expense of survival. Faster growing juveniles have a higher mortality rate (*Lowery, 1988*). Such a conclusion is likely to be of great importance for individuals wishing to culture crayfishes under controlled conditions and reflects the susceptibility of the moulting process to external influences (*Lowery, 1988*).

Very little is known regarding thermal tolerances and temperature preferences of crayfishes. Obviously, as cold-blooded animals, crayfishes are continually exposed to changes in temperature that directly affect their metabolic rate. Temperature also serves as a cue for behavioural arousal from either seasonal hibernation or from their daily hiding places. As a result, water temperature plays an important role in the behavioural ecology of crayfishes (*Hobbs III, 2001*). In temperature preference studies, temperatures selected and subsequently preferred by crayfishes are around 20˚C (68˚F) (*Lodge and Hill, 1994*). It is thought that most crayfishes exhibit upper temperature tolerances ranging between 32-36˚C (90-97˚F) after which crayfishes start to die. In general, crayfishes are found to be relatively inactive at water temperatures below 10-15˚C (50-59˚F) and above 25-30˚C (77-86˚F) (*Huner et al., 1991*). Lower thermal tolerance data for crayfishes is lacking, however, the 1-4˚C (34-39˚F) temperatures that occur under ice during Canadian winters is not acutely lethal to any cool water species.

Calcium Availability

The moulting process in crayfishes results in the loss of a significant portion of calcium bound within the cast exoskeleton. As a result, crayfishes must replace a portion of lost calcium from both food and water. It is common knowledge among culturists that crayfishes reared in environments with a low concentration of calcium produce thin exoskeletons. For example, lakes and streams with low pH values, such as those found on Ontario's Precambrian shield, are generally low calcium environments. It has been observed that low calcium availability in these aquatic ecosystems results in reductions in carapace rigidity in *Orconectes* sp. thereby presumably increasing the susceptibility of crayfishes to fish predation and resultant reductions in the foraging activity of these crayfishes.

Investigations have also shown that the geographic distribution of crayfishes are related to natural levels of calcium in water associated with the soluble components of regional deposits of both chalk and limestone (*Greenaway, 1985; Lowery, 1988*). The lower tolerance limits of crayfishes for available calcium in freshwater ecosystems is thought to be around 5 mg/l (5ppm) (*Hogger, 1988*). Several studies have shown the importance of calcium for the survival of crayfishes but there is little information available regarding the role and importance of calcium for the growth of crayfishes (*Hogger, 1988*).

Low pH Environments

Direct physiological impacts to crayfishes as a result of living in low pH environments are possible. In adult *O. virilis* (Virile Crayfish), it has been demonstrated that calcium uptake is impaired below a pH of 5.75 and is totally inhibited below pH 4.0. Since crayfishes are capable of extensive movement it was thought by *France (1985b)* that *O. virilis* (Virile Crayfish) should be able to avoid aquatic habitats affected by low pH associated by moving into deeper less acidified waters. However, no avoidance behaviour of this crayfish species to low pH was observed, although this pH level was causing reproductive problems. The inability of *O. virilis* (Virile Crayfish) to detect and avoid acidic waters could therefore interfere with reproduction (*France, 1985b; Hobbs III, 2001*). It was concluded that prolonged survival of *O. virilis* (Virile Crayfish) in waters receiving acid runoff was doubtful (*France, 1985b; Hobbs III, 2001*).

In addition, juvenile crayfishes are more sensitive to low pH than adults (*France, 1984; Berrill et al., 1985*). Acid tolerance limits for adult *Orconectes* sp. are within the pH range of 5.5-6.1. The distribution and types of crayfish species found together has been linked to geographical differences in environmental acidity (*Berrill et al., 1985; Hollett et al., 1986; Di Stefano et al., 1991; France 1993*). In a study of 36 soft-water lakes in central Ontario the distribution and abundance of crayfishes was found to depend upon lake pH (*France, 1993*). *France and Collins (1993)* concluded that acid rain has caused the local extinction of *Orconectes* sp. crayfish population in a number of low pH and low alkalinity lakes in Ontario. The higher tolerance (pH 4.0-4.5) of *C. robustus* (Robust Crayfish) and *C. bartonii* (Appalachian Brook Crayfish) (*Wood and Rogano, 1986; Taylor et al., 1995; Taylor 1995 unpublished*) makes *C. robustus* (Robust Crayfish) the only candidate suitable for commercial exploitation in low pH lakes (*Lodge and Hill, 1994*).

Water Velocity

Adaptations by crayfishes to variations in current has allowed crayfishes to occupy a wide range of habitats (*Hogger, 1988*). In terms of morphology, *Alexander (1971)* hypothesized that the sprawling posture of crayfish walking legs was an adaptation to withstand overturning in strong lateral currents (see also *Maude and Williams, 1983*). It has been demonstrated that when crayfishes are exposed to increases in current velocity, they alter their body posture to counteract the effects of drag and to maintain position (*Maude and Williams, 1983*). Such an ability to control movements through flowing water are important. As crayfish species differ in their ability to deal with water currents, inherent differences between species can govern habitat choice and subsequent species distributions (*Bovjberg, 1952, 1970; Caine, 1978*). For example, the superior streamlining capabilities of *C. bartonii* (Appalachian Brook Crayfish), *O. propinquus* (Northern Clearwater Crayfish) and *O. rusticus* (Rusty Crayfish) helps to explain the occurrence of these species in fast flowing rivers, whereas, the inability of other species (e.g. *O. immunis* – Papershell Crayfish) to exist in high velocity environments limits the potential of certain species to expand their geographical ranges (*Hogger, 1988*).

Dissolved Oxygen

The major water quality problem in outdoor crayfish aquacultural enterprises is low dissolved oxygen (DO). Low dissolved oxygen in aquatic environments is often the result of high biological oxygen demands (BOD) associated with the rapid biological decomposition of organic material by decomposers such as bacteria which use oxygen. Biological oxygen demand is generally highest during warm periods when water temperatures rise causing increases in the metabolic and subsequent biological activity of decomposers. Many crayfish species begin to show signs of low dissolved oxygen stress at levels below 3 mg/l (3 ppm). Laboratory investigations have shown that *O. virilis* (Virile Crayfish) and *O. propinquus* (Northern Clearwater Crayfish) begin to die when dissolved oxygen concentration drops below 1.5 mg/l (1.5 ppm). Dissolved oxygen in any culture system should be held at least 3.0 mg/l and as close to saturation as possible (*Huner, 1988*). However, certain crayfish species such as *O. immunis* (Papershell Crayfish) along with the obligate semi-terrestrial burrowers *F. fodiens* (Chimney Crayfish) and *C. diogenes* (Devil Crawfish) are adapted to tolerate lower levels of dissolved oxygen.

In lakes with an absence of oxygen below a certain depth, crayfishes can be excluded from these environments (*Fast and Momot, 1973*). This restriction in potential habitat use could be alleviated by aerating these deeper regions of lakes and ponds. This would increase the available habitat for crayfishes and also raise temperature, in turn increasing crayfish growth (*Lodge and Hill, 1994*). However, such a procedure has some obvious economic and logistical shortcomings. In addition, since hypoxia (an absence of dissolved oxygen) under winter ice is common in moderately productive lakes, the potential for winter-kill to limit crayfish populations is also strong (*Lodge and Hill, 1994*). It is possible that lakes exist that provide good summer conditions for crayfish production but lack reproducing populations of crayfishes because of winter-kill. If such lakes exist, winter aeration could be considered but, again, this would be costly (*Lodge and Hill, 1994*).

Habitat Availability

Even crayfishes that inhabit open water very seldom live on clear, sandy bottom areas where there is no natural cover. In shallower waters, crayfishes typically conceal themselves under rocks, in crevices, among aquatic vegetation or in underwater burrows. Crayfishes inhabiting shallow mud bottomed ponds are sometimes protected from the view of predators by abundant aquatic vegetation and elevated turbidities through the suspension of clay or silt particles.

For the most part, if there are refugia available, crayfishes will hide under it. Many temperate crayfish species are solitary, occupying and defending refugia in coarse substrate (e.g. cobble, but see *O. immunis* – Papershell Crayfish). Rocky bottoms provide an abundance of hiding places and constitute the most common type of crayfish habitat in Ontario. Refugia of this nature allows for shelter from water currents, competitors and predators. If the substrate beneath the rocks is gravel or stone, crayfishes are largely restricted to crawling under rocks where there is some sort of natural space. This appears to be true for *O. virilis* (Virilie Crayfish), *O. propinquus* (Northern Clearwater Crayfish), *O. rusticus* (Rusty Crayfish), *C. robustus* (Robust Crayfish) and *C. bartonii* (Appalachian Brook Crayfish). *O. propinquus* (Northern Clearwater Crayfish) has also been observed in ponds and lakes where there are many flat stones lying on a clay mud substrate (*Crocker and Barr, 1968*). *Capelli and Magnuson (1983)* in a study that related *Orconectes* crayfish abundance in 67 northern Wisconsin lakes to various factors concluded that substrate refugia is the single most important factor limiting the abundance of crayfishes in natural habitats. This relationship between substrate type and crayfish abundance indicate that densities of adult crayfishes increases with increasing crevices as refugia. An obvious exception to this are burrowing *O. immunis* (Papershell Crayfish).

BIOTIC FACTORS

Competition for Habitat

Competition for shelter as habitat is also related to both the size of a crayfish and prior ownership of the habitat (*Lodge and Hill, 1994*). In general, larger crayfishes win more aggressive competitive encounters than smaller crayfishes. Crayfishes occupying crevices as hiding places throughout rocky substrate (e.g. cobble) are usually found to be solitary, aggressive and defensive of such crevices. Laboratory studies have also demonstrated that crayfishes behave aggressively towards one another when shelter as habitat is in short supply (*Capelli and Munjal, 1982; Capelli and Hamilton, 1984; Lodge and Hill, 1994*). This observation lends support to the idea that competition for potentially limiting resources such as hiding places may be a common occurrence among surface water crayfishes.

However, under certain circumstances such competitive behaviour may change. For example, laboratory investigations have also revealed when very high densities of *O. virilis* (Virile Crayfish) occur together, individuals of this species are less aggressive towards one another and when habitats are created which contain few crevices relative to the number of crayfishes present, multiple crevice occupancy is often observed. Moreover, if ample crevices are provided then single crevice occupancy is always the rule (*Bovbjerg and Stephan, 1975; Hogger, 1988*). This may be of interest to crayfish culturists wishing to hold and culture large numbers of crayfishes.

Competition for Food

Competition for food may also occur among crayfishes. There are a number of possible effects that may arise when increased competition for food occurs as a result of an increased abundance of crayfishes. Such effects can include decreased survival of the more abundant age classes, increased time until first reproduction, increased time between reproductive bouts (*Huner et al., 1990*) and decreased fecundity of surviving females (*Lodge and Hill, 1994*). *France (1985)* studying *O. virilis* (Virile Crayfish) in six lakes in the Experimental Lakes Area (ELA) of Ontario found that a positive relationship exists between food availability and growth of *O. virilis* (Virile Crayfish). This means that the growth of crayfishes in these lakes appears to be limited by food availability.

Species Overlap and Replacement

When the distributions of two or more crayfish species overlap, the primary behavioural response is generally aggressive (*Hogger, 1988*). Between crayfish species such aggressive behaviour ensures that the most viable species to occupy a particular habitat will succeed (*Hogger, 1988*). For example, in northern Wisconsin (*Lodge and Hill, 1994*) and Ontario (*Berrill, 1978*) *O. rusticus* (Rusty Crayfish) is replacing native *O. virilis* (Virile Crayfish) and *O. propinquus* (Northern Clearwater Crayfish). A number of replacement mechanisms have been proposed to explain this phenomenon. Research suggests that between species competition for habitat (crevices as refugia) can result in competitive exclusion of one species by another (*Penn and Fitxpatrick, 1963; Aiken, 1965; Bovbjerg 1970; Berrill, 1978; Capelli and Munjal, 1982; Flynn and Hobbs, 1984; Rabeni, 1985; Lachat and Laurent, 1988; Hazlett* *et al., 1992; Lodge and Hill, 1994; Lodge et al., 2000; Hobbs III, 2001*). Many authors implicate the aggressive nature and inherently larger body size of *O. rusticus* (Rusty Crayfish) as two primary factors contributing to the ability of *O. rusticus* (Rusty Crayfish) to displace other crayfish species from previously occupied habitats.

O. rusticus (Rusty Crayfish) also has a competitive advantage over other species of crayfishes as *O. rusticus* (Rusty Crayfish) eggs hatch earlier than those of *O. propinquus* (Northern Clearwater Crayfish) or *O. virilis* (Virile Crayfish). The crayfish *O. rusticus* (Rusty Crayfish) also has a higher intrinsic growth rate (*Hill et al., 1993*). This means that *O. rusticus* (Rusty Crayfish) offspring are larger than immature *O. virilis* (Virile Crayfish) and *O. propinquus* (Northern Clearwater Crayfish) of the same age. Also, *O. rusticus* (Rusty Crayfish) males have large chelae and at maximum adult length is considerably larger than either *O. virilis* (Virile Crayfish) and *O. propinquus* (Northern Clearwater Crayfish). In addition, *O. rusticus* (Rusty Crayfish) has been shown to be superior to other species in detecting and consuming food (*Olsen et al., 1991; Willman et al., 1994*). Such evidence strongly suggests that between species competition is most certainly an important mechanism by which *O. rusticus* (Rusty Crayfish) replaces other crayfish species (*Lodge and Hill, 1994; Lodge et al., 2000*).

Hybridization

Another possible mechanism causing the displacement of one crayfish species by another is the occurrence of between species mating and the potential for hybridization (*Hogger, 1988*). Between species matings are commonly observed where species distributions overlap. However, only a few instances of genuine hybrid species arising from between species mating have been documented (*Hogger, 1988*). For example, matings of *O. propinquus* (Northern Clearwater Crayfish) and *O. virilis* (Virile Crayfish) with male *O. rusticus* (Rusty Crayfish) are much more common than matings of female *O. rusticus* (Rusty Crayfish) by male *O. propinquus* (Northern Clearwater Crayfish) and *O. virilis* (Virile Crayfish) (*Capelli and Capelli, 1980; Berrill, 1985*). Between species matings are thought (in part) to be the outcome of an inability a given crayfish species to find same species mates as a result of reduced population sizes caused by unfavorable environments and shifts in the community structure of crayfishes (*Hogger, 1988*). *Capelli and Capelli (1980)*, in a study examining the morphometric traits of both *O. rusticus* (Rusty Crayfish) and *O. propinquus* (Northern Clearwater Crayfish) co-existing in some northern Wisconsin lakes, found that up to 27% of the population consisted of hybrids. For hybridization to play a role in species replacements it must reduce fitness of one species more than another and the hybrids must be at a selective advantage (*Hogger, 1988*). However, the disappearance of hybrids in lakes as an "invasion front" drives native crayfish species extinct suggests that reproductive success of hybrids is low at best (*Capelli and Capelli, 1980; Lodge and Hill, 1994*).

Predator Avoidance

The presence of predators elicits various behavioural responses in crayfishes. Fishes often consume a large fraction of crayfishes in a given population (*Rabeni 1992; Roell and Orth, 1993*) and evidence suggests that predation by fishes can significantly reduce the population abundance of crayfishes (*Lodge and Hill, 1994*). Smaller crayfishes are subject to much higher predation rates than larger crayfishes. Some species are at an inherent disadvantage from predation. For example *O. virilis* (Virile Crayfish) has no size disadvantage but it suffers more from fish predation because it engages in behaviour such as increased swimming and foraging that puts it more at risk than other species such as *O. rusticus* (Rusty Crayfish) (*DiDonato and Lodge, 1993; Garvey et al., 1994; Lodge and Hill, 1994*). Under ideal conditions, many crayfishes, when given a choice, will use hiding or burrowing in refugia to avoid detection by predators. When discovered however, if a hiding place is not nearby, crayfishes attempt to escape by back-swimming. If escape is not possible, crayfishes will often assume a defensive posture called the predator response posture. As crayfish populations expand they may be confronted with the possibility of resource depletion (e.g. habitat, food) and subsequently, the very real possibility of attracting more predators. Both of these factors are thought capable of limiting crayfish population size.

TAXONOMIC KEY TO ONTARIO CRAYFISHES

See glossary for explanation of scientific terms. Figures 12-15 are located directly after this list.

1a. Rostrum with lateral spines (Figure 12),
male stylets directed forward (Figure 14).. 5 Genus *Orconectes*

1b. Rostrum without lateral spines,
male stylets directed ventrally 2

2a. Opposable margin of dactyl of chela without
angular notch in proximal half (Figure 13);
cervical groove interrupted laterally (Figure 12) ....Genus *Fallicambarus*
Fallicambarus fodiens

2b. Opposable margin of dactyl of chela without angular
notch in proximal half (Figure 13)...3 Genus *Cambarus*

3a. Cervical groove continuous laterally (Figure 12)...*Cambarus diogenes*

3b. Cervical groove not continuous laterally (Figure 12)..4

4a. Inner margin of palm with one row of tubercles (Figure 13); rostrum square, tapering acutely to its tip (Figure 12); carapace without lateral spines (Figure 12); tip of mesial process of male From I stylets pointing ventrally (Figure 14) ....*Cambarus b. bartonii*

4b. Inner margin of palm with two rows of tubercles (Figure 13); rostrum rectangular not tapering abruptly to its tip (Figure 12); carapace often with lateral rostral spines; tip of mesial process of Form I male stylets pointed dorsally (Figure 14).....................................*Cambarus robustus*

5a. With carina on rostrum (Figure 12); Form I male stylets without a distinct right-angled shoulder on anterior margin; tips of mesial process in male stylets acutely pointed in lateral view (Figure 14)......*Orconectes propinquus*

5b. Without carina on rostrum (Figure 12) 6

6a. Dactyl of chela with notch at base of inner side (Figure 13), stylets weakly curved ventrally (Figure 14); terminal process strongly curved caudally and sub-equal in length, longer and narrower than in *Cambarus* ....*Orconectes immunis*

6b. Dactyl of chela without notch at base of inner side 7

7. First pleopods with tips of equal length 8

8a. With row of spines in front of cervical groove, distinct chestnut pattern of mottling on abdomen ....*Orconectes limosus* (Quebec)

8b. Without spines in front of cervical groove; Form I male stylets with distinct, right-angled shoulder on anterior margin (Figure 14) ....*Orconectes obscurus*

9. First pleopods with tips of clearly unequal length 10

10. Sides of rostrum slightly concave; fingers of chelae long and narrow with distinct black bands near tips; distinct lateral rusty spots on carapace; Form I male stylets longer than mesial process (Figure 15); seminal receptacle oval (Figure 15) ....*Orconectes rusticus*

Fingers of chela broader; tuberculate and without bands on tips; carapace with rusty spots; body with green-brown mottling; terminal process of Form I male stylets weakly curved caudally; the lateral longer than mesial (Figure 14); fossa of seminal receptacle long and narrow (Figure 15) ....*Orconectes virilis*

FIGURE 12: *Carapaces of Form I males of the nine Ontario crayfish species. Dorsal view. (With permission from the Royal Ontario Museum (ROM), C.N. Storwick – artist).*

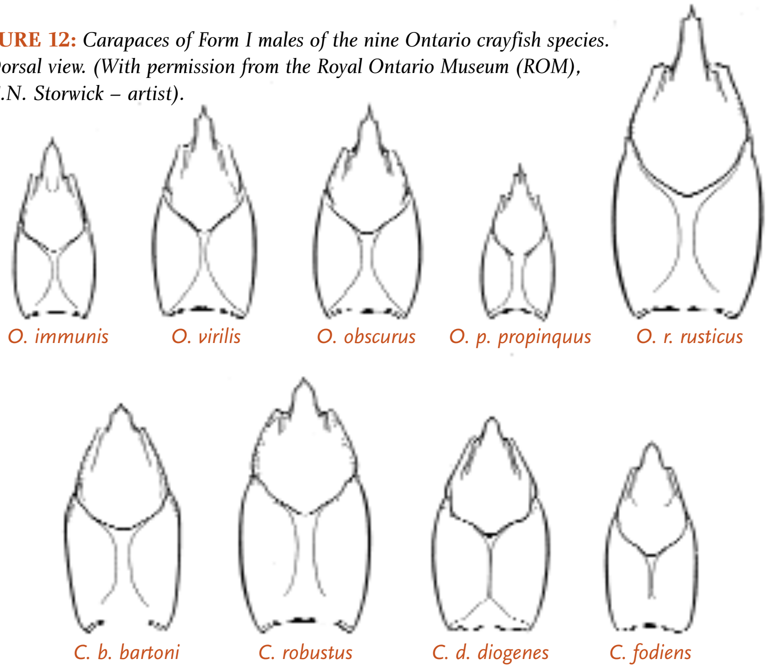


FIGURE 13: *Distal great cheliped segments of eight of nine Ontario crayfish species. All specimens are right appendages of Form I males. (With permission from the Royal Ontario Museum (ROM), C.N. Storwick – artist).*

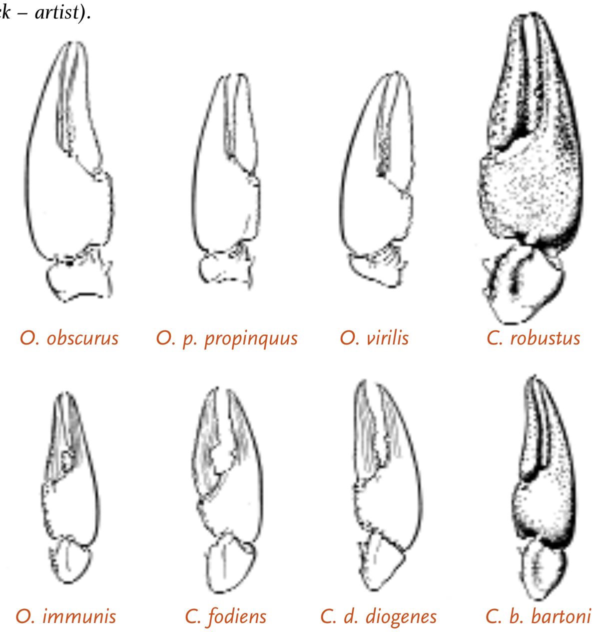


FIGURE 14: *Form I right copulatory stylets of the nine Ontario crayfish species. Lateral view. (With permission from the Royal Ontario Museum (ROM), C.N. Storwick – artist).*

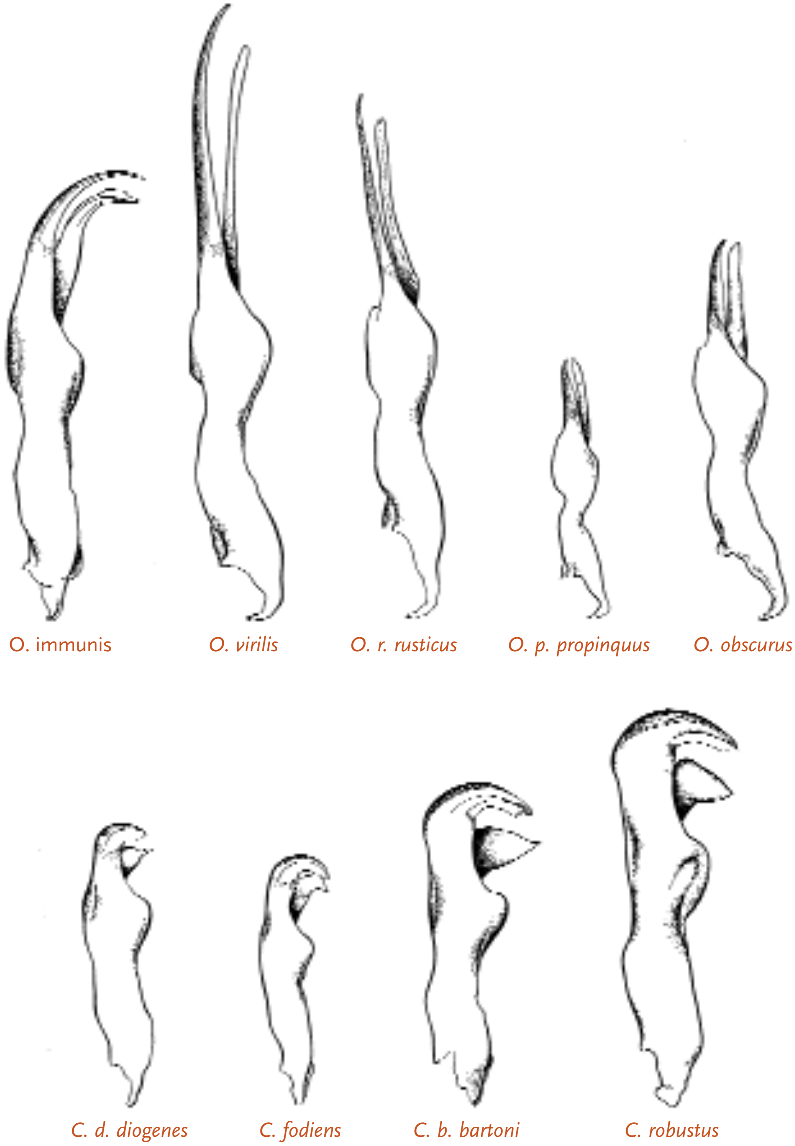
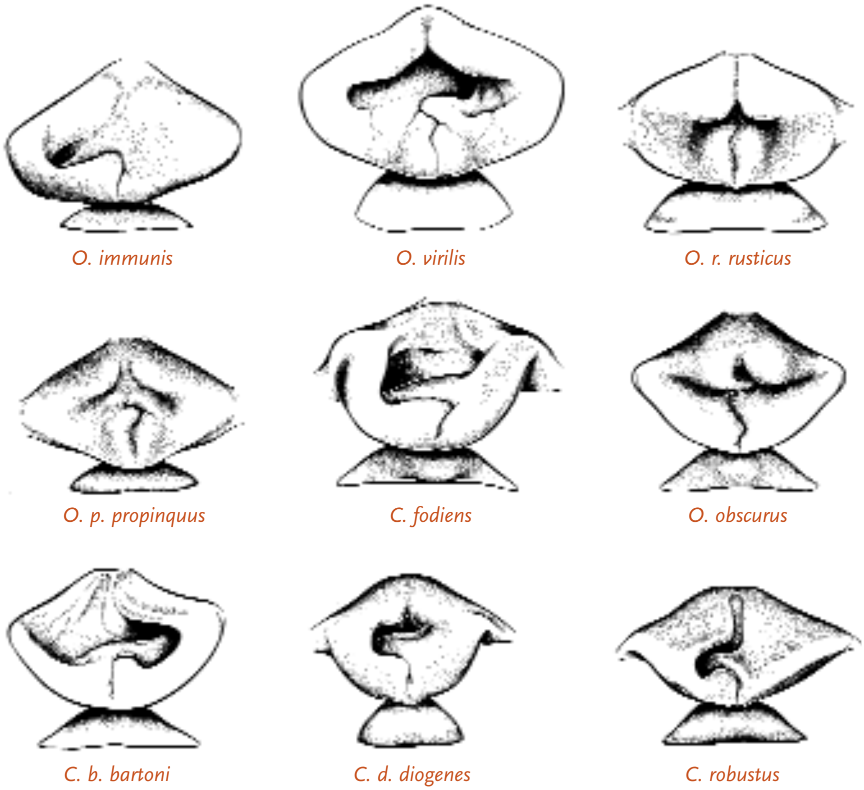


FIGURE 15: *Seminal receptacles of mature females of the nine Ontario crayfish species. Anterior edge towards top of page. (With permission from the Royal Ontario Museum (ROM), C.N. Storwick – artist).*



SUMMARY OF CRAYFISH FAUNA OF ONTARIO

SPECIES/COMMON NAME	HABITAT
Natural Species	
Fallicambarus fodiens (Cottle) Chimney or Digger Crayfish	Ontario: roadside ditches, farm fields and irrigation ditches, natural wetlands.
Cambarus diogenes (Girard) The Devil Crawfish	Ontario: natural wetlands.
Cambarus bartonii bartonii (Fabricius) The Appalachian Brook Crayfish	Ontario, Quebec, New Brunswick: lakes, fast flowing rivers and streams.
Cambarus robustus (Girard) The Robust Crayfish	Ontario, Quebec: lakes rivers and streams.
Orconectes propinquus (Girard) The Northern Clearwater Crayfish	Ontario, Quebec: rivers, streams and lakes
Orconectes immunis (Hagen) The Papershell or Calico Crayfish	Ontario, Quebec, Manitoba: farm and natural ponds, lakes, ditches and slow streams and stagnant water.
Orconectes virilis (Hagen) The Virile Crayfish	Ontario, Quebec, Manitoba, Saskatchewan, Alberta: rivers, streams and lakes
Introduced Species	
Orconectes obscurus (Hagen) The Obscure Crayfish *(introduced from northern US; Ontario: Southern, North-central, North-east)*	Ontario: streams and lakes
Orconectes rusticus rusticus (Girard) The Rusty Crayfish *(introduced from northern US; Ontario: Southern and Northwestern)*	Ontario: streams, ponds and lakes

-12-

Common Infectious Diseases, Parasites and Predators of Crayfishes

OVERVIEW

Crayfishes are vulnerable to a wide range of diseases. However, diseases that are not associated with the loss of large numbers of crayfish remain relatively undetected and ignored (*Alderman and Polgase, 1988*). Disease in crayfishes can be caused by bacteria, fungi and protozoa along with parasites. However, the importance of the pathologies associated with these organisms is not well understood. As of yet, there are very few effective treatment methods known for the various diseases of crayfish (*Alderman and Polgase, 1988*).

BACTERIAL DISEASES

Bacterial infections in freshwater crayfishes are thought occur primarily from wounds created through aggressive encounters, overcrowding and poor water quality (e.g. high water temperatures and low dissolved oxygen) (*Huner, 1994*). Overall, bacterial pathogens that can potentially cause life threatening infections in freshwater crayfish include species of the genera *Aeromonas, Bacillus, Corynebacterium, Mycobacterium, Flavobacterium, Pseudomonas, Vibrio, Edwardsiella, Acinetobacter, Arthrobacter, Proteus* and *Citrobacter,* (*Alderman and Polgase, 1988; Huner, 1994*). Species belonging to these genera are often associated with stagnant water, high temperatures and decomposing vegetation such as those associated with poorly managed crayfish production ponds (*Huner, 1994*). These bacterial pathogens have been isolated from the crayfish blood, digestive tract and exoskeleton (*Huner, 1994*).

BLOOD INFECTIONS

Although the overall impact of blood infections on the crayfish industry is unknown, high levels of bacteria associated with water temperatures greater than 27˚C (81˚F), low dissolved oxygen (DO) levels, transport from ponds to intensive systems or a combination of these factors may all affect crayfish production (*Huner, 1994*). Gross clinical symptoms of blood infections include lethargy, slow response (e.g. inability of a crayfish to right itself) and limb tremor as a result of neuromuscular dysfunction (*Alderman and Polgase, 1988*). Toxins produced and secreted as waste from infectious bacteria are thought to be the cause of death in infected crayfishes (*Alderman and Polgase, 1988*).

DIGESTIVE TRACT INFECTIONS

In low numbers bacteria form a natural part of the flora of the crayfish digestive tract. However digestive tract infections can occur involving bacteria belonging to this bacterial flora. Crayfish digestive tract infections are thought to also arise as a result of unfavorable environmental conditions (e.g. high water temperatures, low dissolved oxygen). Such factors weaken the crayfish immune system and predispose the animal to infection by opportunistic bacteria (*Alderman and Polgase, 1988*). Again, poor water quality, overcrowding and competition are the primary factors leading to stress and tissue wounding. Under these situations, infections by opportunistic bacteria, can proliferate and cause widespread mortalities. Anti-microbial agents such as treatment oxlinic acid baths may be effective but are time consuming (*Alderman and Polgase, 1988*).

BURNSPOT DISEASE

The hard chitinous exoskeleton provides crayfishes with an effective barrier against the invasion of most microorganisms (*Huner, 1994*). However, "chitin eating" bacteria attack crayfish exoskeletons where the outer epicuticle has been broken. These chitinoclastic bacteria cause a syndrome in crayfish and other crustaceans known as "Burnspot Disease". Burnspot is common amongst all crustaceans worldwide (*DFO, 1994*). Infections break down the chitin within a crayfish exoskeleton. Lesions appear which look like burn marks and are due to the tanning of a wound or damaged area of the exoskeleton associated with various bacteria. Cases of Burnspot generally involve only the exoskeleton and there is no physiological response by the crayfish to the infection other than tanning of the infected region. It most cases the lesion disappears during the next moult when the crayfish exoskeleton is shed. More severe lesions may persist through the moult and can lead to secondary blood infections and to death (*Alderman and Polgase, 1988*). Such infections are enhanced by poor environmental conditions. Crayfishes are most susceptible to exoskeletal infections when wounds, parasites, or physiological imbalances have caused the epicuticle of the crayfish exoskeleton to rupture (*Amborski et al., 1975; Alderman and Polgase, 1988; DFO, 1994*). Lesions associated with Burnspot disease have been treated successfully by dipping the infected animal in absolute alcohol for 10 sec. and then rinsing it in sterile water (*Alderman and Polgase, 1988*) Bath treatments with oxolinic acid 10 mg/l (10 ppm) have also been used to treat Burnspot. Lightly infected animals recovered after a single 1-hour bath and lesions disappeared at the next moult. Such treatment is most applicable to commercial operations producing crayfish for human consumption where visual appearance of the product is an important consideration (*Alderman and Polgase, 1988*).

GILL DISEASE

Gill disease is a term used to describe excessive growth of bacteria on the gills and sometimes on the body surface of the crayfishes as well. Similar to the conditions that promote the proliferation of both blood and digestive tract infections, gill disease is also linked to poor water quality, overcrowding and competition. Growth of bacteria is related to prolonged intermoult periods associated with crayfishes in which growth is complete. However, gill disease is thought especially serious as it also has a tendency to affect early juvenile stages of crayfish development as well. Infections of gill disease can be controlled using antibiotics but this treatment can be expensive (*Alderman and Polgase, 1988*).

FUNGAL DISEASES

CRAYFISH PLAGUE

Crayfish plague is caused by the fungi *Aphanomyces astaci* and is thought to have arisen in Lombardy, Italy in the 1860s following the introduction of North American crayfishes into local river systems (*DFO, 1996*). Crayfish plague is common everywhere throughout in North America. However, native North American crayfishes are resistant to the disease. As such, crayfish plague is primarily a European disease which only recently in 1981 gained entry into Britain (*DFO, 1996*). Again, unlike many European species, North American crayfishes – although vectors of transmission – are highly resistant to infection by crayfish plague.

There are no known hosts of *A. astaci* other than crayfishes and the fungus does not survive well without a crayfish as a host (*Alderman and Polgase, 1988*). The fungus attacks the soft cuticle in the joint or between segments through the growth of fungal hyphae on the soft, non-calcified parts of the cuticle and possibly along the nerve cord. Crayfish plague can kill a crayfish within a week or two (*Huner, 1994*). Crayfish plague has ruined many European and Scandinavian crayfish fisheries since its introduction with commercial loses reported in the many millions of dollars (*Holdich, 1988*).

PROTOZOAN DISEASES

PORCELAIN DISEASE

Microsporidosis (commonly known as "Porcelain Disease") in crayfishes, is due to the protozoan genera *Thelohania* (*Huner, 1994*). Porcelain Disease derives its name from the opaque milky china white appearance of crayfish muscle tissue infected with developing spores (*Huner, 1994*). Despite the lapse of a century, Porcelain Disease is still not fully understood (*Alderman and Polgase, 1988*). Prior to death, reduced muscle strength of infected animals is often noted (*Alderman and Polgase, 1988*). Crayfishes with advanced infections are noticeably lethargic and have an ineffectual "tail-flip" (*Huner, 1994*). Death is inevitable for crayfishes infected with Porcelain Disease. Mortality is the result of the destruction of muscle tissues within the animal (*Alderman and Polgase, 1988*). Survival times vary and range between 5 months to 2 years (*Alderman and Polgase, 1988*). Porcelain Disease is a lethal parasitic infection and is thought to be the most serious disease of crayfishes in the world after crayfish plague (*Alderman and Polgase, 1988*).

Porcelain Disease has been found worldwide in an extensive range of European species and has been attributed as cause of epidemics among crayfishes in Europe (*DFO, 1994*). Records of Porcelain Disease in the United States are relatively few (*Alderman and Polgase, 1988; DFO, 1994*). Porcelain Disease has not yet been reported in Canada (*DFO, 1994*). The economic consequences of Porcelain Disease for intensive and semi-intensive crayfish operations can be potentially severe. The only effective counter measure against the spread of Porcelain Disease is to remove all individuals showing signs of infection (*Alderman and Polgase, 1988*) and to carefully monitor vectors of transmission. No treatment at present is available but buquinolate and fumagillin are suggested when attempting to treating microsporidian infection (*Huner, 1994*).

COMMENSAL PROTOZOANS

Protozoans are associated with freshwater crayfishes as commensals. This means that although they reside on the crayfish body they pose no overall harmful effect to the crayfish host. A number of different protozoans reside on the exoskeleton of crayfishes. Although they can occur all over the crayfish body, both moving and stationary protozoan forms are generally more frequent around the gills and limb joints (*Alderman and Polgase, 1988*). Overall, the abundance and types of protozoans living as commensals on the crayfish body varies with crayfish species, environmental conditions and the moulting stage of the animal (*Huner, 1994; Alderman and Polgase, 1988*). The presence, diversity and abundance of any particular group of commensal protozoans also depends upon water quality (*Huner, 1994*).

Generally, commensal protozoans tend to proliferate in habitats containing elevated levels of organic particulate material and, subsequently, elevated levels of bacteria in the water column often associated with commercial crayfish ponds (*Alderman and Polgase, 1988*). Preening and moulting of the exoskeleton by crayfishes reduces the abundance of commensal protozoans on the crayfish body. However, depending upon environmental conditions, commensal protozoans are still capable of proliferating beyond manageable levels (*Alderman and Polgase, 1988*). Commensal protozoans are thought not to damage the crayfish gill surface (*Vogelbein and Thune, 1988*) but their presence may result in increased susceptibility to low dissolved oxygen levels due to decreased gill surface area and impaired water flow through the gill chambers. However, crayfishes have been observed to tolerate heavy gill and exoskeleton infestations with no visible pathological effects. Mortalities as a direct result of epicommensal parasites is so far undocumented (*Huner, 1994*). Much more information on the effects of these organisms and on means of control is needed (*Alderman and Polgase, 1988*).

PARASITIC WORMS

TREMATODE WORMS

Most trematode worms that parasitize crayfishes result in what are called metacercarial infections. Juvenile trematodes worms develop into adult worms when ingested by an appropriate crayfish host (*Huner, 1994*). It is the juvenile trematodes that are generally found in crayfishes, although there are some are examples of adult trematode worms infecting crayfishes. As highly effective parasites, trematode worms are highly adapted to their various locations within their crayfish host and there is little pathological response by crayfishes as hosts (*Alderman and Polgase, 1988*). Overall, the majority of trematode worms infecting crayfishes are thought to be harmless. However, the wound produced by the invading trematode worms may provide an entry for secondary bacterial infections. In addition, the passage of juvenile trematode worms through the body tissues of the host can cause potentially serious damage which can result in indirect mortalities (*Alderman and Polgase, 1988*). Reports of crayfish trematode worm infections are global and common in crayfishes from America, Asia and Europe (*Alderman and Polgase, 1988*). However, reports of crayfish trematode infections are few in Canada and its significance is deemed negligible (*DFO, 1994*).

SPINY-HEADED WORMS

The second group of parasitic worms found in crayfishes are the Spiny-Headed worms which are characterized by a complex life cycle involving two or more hosts (*Huner, 1994*). Spiny-Headed worms are small with typical adults being only a few millimetres long (*Alderman and Polgase, 1988*). In crayfishes, Spiny-Headed worms are represented by a single species. In all reported cases, Spiny-Headed worms have been found encysted on the outside of the crayfish intestine, generally at the point at which it passes from the thorax to the abdomen. Cysts have the appearance of a small pink grain of rice (*Alderman and Polgase, 1988; Huner, 1994*). Spiny-Headed worm infestations generally remain at low levels and are not thought to have a detrimental effect upon the crayfish host. However, heavy infestations may have a serious debilitating, perhaps lethal, effect (*DFO, 1994*). In addition, the lesion caused by the parasite as it traverses the gut wall could act as an area susceptible to secondary infections by pathogenic bacterial organisms. Although not common, Spiny-Headed worms have been reported in crayfishes from Europe, America, and Australia (*Huner, 1994*).

FLATWORMS

Crayfishes can be infested by flatworms. This condition being known as "Turbellaria of Crayfish" or "Temnocephalan Infestation". North America has only one species of flatworm that infests crayfishes (*DFO, 1997*). Flatworms normally inhabit the external surfaces, especially the crevices around the appendages of crayfishes, though some live in the gill chambers or on the mouthparts (*Alderman and Polgase, 1988; DFO, 1997*). Crayfishes provides a substrate for attachment for the flatworms and are thought to benefit from the ability of the flatworms to remove fouling organisms from the gill chamber (*Alderman and Polgase, 1988*). Flatworm eggs are laid in thick capsules cemented to the crayfish exoskeleton. Miniature adult worms hatch from the egg. Eggs laid on the exoskeleton of the host which moults are lost unless they have a method of transfer to the new exoskeleton. Flatworm egg masses cemented to the host crayfish exoskeleton are also a potential site of secondary infection for bacterial pathogens and are unsightly and adversely affect the marketing of crayfish for human consumption (*DFO, 1997*). Flatworms have a low tolerance for high salinity. Submerging a crayfish in a bath of 50% seawater for 2-4 hours can be effective in destroying flatworms. Also, a 15-minute bath in 0.5% formalin has been used to reduce flatworm infestations (*DFO, 1997*). Although these treatments are effective against the flatworms, the egg stage is much more resistant requiring that treatments be reapplied after they have hatched (*DFO, 1997*)

BRANCHIOBDELLIDA WORMS

Some branchiobdellida worms are commensal on crayfish carapaces and some "leech-like" species are parasitic within the gill chambers of crayfish (*Huner, 1994; DFO, 1994*). Where infestations by parasitic species occur on crayfish gills, tanning of the gill filaments is commonplace at points where the parasite has grazed on the host (*Alderman and Polgase, 1988; DFO, 1994*). Constant wounding by the feeding parasitic branchiobdellids may provide a route of entry for other secondary bacterial pathogens. Although the crayfish host is thought be affected by the loss of fluids and by structural gill damage, it is assumed that this damage occurs at levels low enough not to be a direct cause of crayfish mortalities (*Alderman and Polgase, 1988; DFO, 1994*). Less harmful, commensal branchiobdellids are frequently found in much larger numbers than parasitic species on any given host (*Alderman and Polgase, 1988*). Branchiobdellids have been found on crayfishes throughout North America, Europe and Eastern Asia including Japan (*Alderman and Polgase, 1988; DFO, 1994*). In general, their distribution is thought to be ubiquitous, however some species are thought to be host specific. No known method of control is available. Infected crayfish should not be transplanted to other areas (*DFO, 1994*).

PREDATORS OF CRAYFISHES

Mortality of freshwater crayfishes as a result of ageing is a seldom recorded occurrence as predation results in the death of old or weak crayfishes prior to dying naturally. Crayfishes are preyed upon by a wide range of organisms of both aquatic and terrestrial origin. *Crocker and Barr (1968)* reported that in North America crayfishes are prey for at least 46 species of fishes, 10 amphibians, 20 reptiles, 38 birds and 6 mammals including man. The importance of crayfishes as a food source for other animals is thought to in part be seasonal. For example, both smaller juvenile crayfishes and soft-shelled post moult crayfishes are preferred prey items of many fishes (*Hogger, 1988*).

PREDATORY FISHES

Predation by game fishes include lake trout (*Salvelinus namaycush*), rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), smallmouth bass (*Micropterus dolomieui*), largemouth bass (*Micropterus salmoides*), green sunfish (*Lepomis cyanellus*), pumpkinseed sunfish (*Lepomis gibbosus*), bluegill (*Lepomis, macrhirus*), rock bass (*Ambloplites rupestris*), white bass (*Morone chrysops*), white crappie (*Pomoxis annularis*), black crappie (*Pomoxis nigromaculatus*), yellow perch (*Perca flavescens*), walleye (*Stizostedion vitreum*), sauger (*Stizostedion canadense*) and northern pike (*Esox lucius*). Non-game fish predators include bowfin (*Amia clava*), carp (*Cyprinus carpio*), creek chub (*Semotilus atromaculatus*), fallfish (*Semotilus corporalis*), hornyhead chub (*Nocomis biguttatus*), yellow bullhead (*Ameiurus natalis*), and brown bullhead (*Ameiurus nebulosus*) (*Crocker and Barr, 1968*).

PREDATORY AMPHIBIANS

Amphibian predators of crayfishes include the mudpuppy (*Necturus maculosus*) and the bullfrog (*Rana catesbeiana*) which can be found in large numbers in and around outdoor commercial crayfish ponds (*Crocker and Barr, 1968; Huner, 1994*). Reptile predators include the queen snake (*Regina septemuittata*), the snapping turtle (*Chelydra serpentina*), the blandings turtle (*Emydoidea blandingii*), the common map turtle (*Graptemys geographica*), the midland painted turtle (*Chrysemys picta marginata*) and the eastern spiny softshell turtle (*Apalone spinifera spinifera*).

PREDATORY BIRDS

All manner of birds consume crayfishes (*Crocker and Barr, 1968; Huner and Barr, 1991; Huner, 1994*). Various species thought predators of crayfishes include grackles (*Quiscalus quiscula*), American crows (*Corus brachychynchos*), common ravens (*Corus corax*), barred owls (*Strix varia*). In addition, sandhill cranes (*Grus canadensis*), rails (Family: *Rallidae*), ring-billed gulls (*Larus delawarensis*) and eastern belted kingfishers (*Ceryle alcyon*) all prey readily upon crayfishes (*Crocker and Barr, 1968*). Piscivorous ducks, especially mergansers (*Mergus* sp.) and comorants (*Phalacrocorax* sp.) also readily eat crayfish. All herons (Family: *ardeidae*) and ibises (Family: *Threskiornithidae*) also consume crayfishes (*Huner, 1994*).

PREDATORY INSECTS

Predators such as dragonfly nymphs, water bugs (e.g. backswimmers) and the larvae of certain water beetles will also readily attack small juvenile crayfishes (*Hogger, 1988*). Their numbers can reach high levels in crayfish culture ponds where predatory fish are controlled/excluded. Dragonfly (Odonata) naids may reach especially high numbers in crayfish habitats and have been implicated as a significant source of juvenile crayfish mortality (*Huner, 1990*).

NUISANCE AND PREDATORY MAMMALS

The aquatic rodents nutria (*Myocaster coypu*) and the muskrat (*Ondatra ziebethica*) are normally herbivorous but can create problems in crayfish ponds by burrowing through levees and causing collapses (*Huner, 1986b; Huner, 1994*). Predacious semi-aquatic mammals like mink (*Mustella vison*), raccoon (*Procyon lotor*), opposum (*Didelphis marsupialis*) and the river otter (*Lutra canadensis*) do prey upon crayfish but are generally not abundant enough to comsume many crayfish (*Huner, 1994*).

-13-
Crayfish Aquaculture

COMMERCIAL CRAYFISH PRODUCTION PONDS

POND SITE SELECTION

When selecting a site for pond construction, heavy gumbo clay soils are the most suitable as they retain water. However, silty clay and sandy clay soils are also capable of holding water. Preliminary testing of the water holding capacity of soils should always be conducted prior to pond construction (*Huner, 1991*). Failure to do so can lead to the loss of both time and money. Soils that do not retain water must always be avoided.

Another important consideration prior to actually going ahead with pond construction is to determine whether the area selected for construction is under any sort of environmental protection. If this is the case it may be impossible to obtain permission to go ahead with construction. Failure to consult the appropriate authorities could lead to criminal liability. Advisory agencies should always be consulted prior to initiating any construction. Obviously, sites located where there are pre-existing populations of commercial crayfish species are more likely to be successful than those sites without them. Areas with high levels of residual, long lived chlorinated hydrocarbon insecticides such as DDT, endrin, aldrin, dieldrin etc. should be avoided as these substances are highly toxic to crayfishes (*Avault and Huner, 1985; Huner, 1994*).

TYPES OF POND CONSTRUCTION

Crayfish culture ponds are typically of four types: (i) open ponds (ii) semi-wooded ponds (ii) wooded ponds and (iv) rice field ponds (*Huner and Barr, 1991; Huner, 1991, 1994*).

Open crayfish culture ponds are often called permanent ponds and are often constructed on marginal agricultural lands. Such open ponds are generally constructed specifically for the rearing and culture of crayfish for commercial purposes (*Huner, 1994*).

Semi-wooded ponds are those which have been cleared to some degree to aid the growth of crayfish forage crops (e.g. soybeans and sorghums), to facilitate the harvesting of crayfishes and to provide adequate water circulation (e.g. dissolved oxygen and the removal of metabolic wastes) (*Huner, 1991, 1994*). Semi-wooded ponds are generally constructed in low-lying swamp or marsh areas. Construction of these ponds involves simply surrounding the perimeter of the pond site with levees (*Huner, 1994*).

Wooded ponds, although constructed in the same manner as semi-wooded ponds, are typically more difficult to manage when compared to open or semi-wooded ponds as dense vegetation usually associated with both marsh and swamp environments can interfere with water circulation, drainage and the harvesting of crayfishes (*Huner, 1991, 1994*). In addition, high levels of organic material in such ponds can create serious dissolved oxygen problems (high biological oxygen demand) which can result in mass mortalities of pond crayfishes.

Finally, rice field ponds are constructed with elevated levees to allow for increased water depths to accommodate crayfishes. Such ponds may range in size from 0.5-over 200 ha (1.2-494 ac.) in Louisiana. Generally though, rice field pond sizes range typically from 10-20 ha (24.7-49.2 ac.) (*Huner, 1990*).

POND LEVEE CONSTRUCTION

Crayfish ponds require levees that will hold approximately 0.5 m (1.6 ft.) of water when full with an equivalent height for "free-board" to compensate for erosion from wave action (*Huner and Barr, 1991; Huner, 1994*). As such, construction of ponds for commercial crayfish production should be built on relatively level ground using levees between 1.0-1.5 m (3.3-4.9 ft.) high, 2-3 m (6.6-9.8 ft.) wide at the crown and 3-4 m (9.8-13.1 ft.) high at the base (*Huner, 1991, 1994*). Wider levees can be constructed to accommodate vehicles. Levee slopes of 2:1 are commonly used but levees with a 3:1 slope allows for better access to vegetation when using vegetation control equipment such as tractor mowers. When possible, terracing of levees is suggested where levee slopes are steeper to prevent soil erosion and breaching. Well-built levees helps to insure that damage done by burrowing crayfish, mammals and reptiles can be detected and corrected without levee failure and ponds loss (*Huner, 1994*).

Many ponds are constructed with provisions for recirculation canals (*Huner and Barr, 1991; Huner 1991, 1994*). Inner baffle levees are sometimes used to aid in water circulation and recirculation canals are sometimes constructed outside of the perimeter of the pond to help conserve water and reduce pumping costs if pumps are used (*Huner, 1991, 1994*). Some ponds are constructed with water recirculation in mind. Water entering such ponds is normally passed through a passive aeration unit in which water enters through at the highest point, flows through the sections delineated by baffle levees and leaves through a drain at the low end. The drain empties into a canal that extends back to the entry point and is pumped back into the ponds through the aeration unit. This reduces pumping costs especially when the source of pond water is a deep well (*Huner 1994*).

CRAYFISH TRAPS AND HARVESTING

OVERVIEW

North American crayfishes are harvested almost exclusively with baited traps although seines and lift nets can also be effective. The most widely used trap is the traditional style minnow trap: this is a cylindrical device with a cone shaped entrance at either one or both ends (*Huner, and Barr, 1984; Huner 1991*). These particular traps are best suited for total submersion in waters up to 5m (16.4 ft.) deep (*Huner, 1991*). The traditional style minnow trap is not thought to be suitable for harvesting crayfishes from shallow ponds as one end must be propped above the surface to prevent suffocation of crayfishes during periods of low dissolved oxygen often associated with high biological oxygen demands (BOD). The trap design most suitable for capturing crayfishes in shallow commercial ponds in the southern United States (e.g. Louisianna) is a vertical cylinder trap with 2-4 funnel shaped entrances at one end (*Huner, 1991*). The other end is open, but is surrounded by a retainer ring or lid that prevents crayfishes from escaping while metal rods prevent the trap from falling over (*Huner, 1991*) in the shallow mud bottomed waters of crayfish ponds. Floats are often attached to traps to aid in recovery when they are knocked down. Traps can also be constructed in a manner such that they can be compressed laterally so large numbers can be carried in the limited space available in relatively small boats. In North America, over 10 types of ″stand up″ traps are in use, with selection depending upon water depth and the nature of the trap checking system (*Huner, 1991; 1994*).

TRAP SIZES

Trap size can vary considerably with trap heights ranging from 0.67-1.25 m (2.2-4.1 ft.); lengths ranging from 1-1.5 m (3.2-4.9 ft.) long and widths around 0.3 m (1 ft.) (*Huner, 1994*). Traps can be constructed from either plastic or wire hexagonal poultry mesh. Wire poultry mesh or square mesh hardware cloth is often coated with black plastic to retard corrosion of the traps. Traps with coated plastic have been found to capture 10%-20 % more crayfishes than uncoated traps (*Huner, 1988, 1991*). In Louisiana, the most common mesh sizes are 1.9 cm (0.74 in.). However, smaller mesh sizes (e.g. 1.6 and 1.3 cm/0.62 and 0.51 in.) are also frequently used (*Huner, 1990*). Depending upon habitat type, some traps are constructed with heavier wire mesh or netting. Heavy wire or mesh is needed in rocky riverine and lacustrine environments where traps are subject to the actions of currents and waves. Traditional minnow traps can be used in harsher environments such as fast flowing rivers or streams. Such traps are generally set with one entrance facing downstream in areas with currents as crayfishes approach from downstream, being attracted by the scent of bait (*Huner, 1990*). Commercial crayfish traps are generally checked once or twice per day (*Huner, 1994*) depending upon the abundance of crayfishes. Escape rates can be high when trap set time exceeds 24 hours (*Huner, 1994*).

COMMERCIAL HARVESTING

In commercial crayfish bait (e.g. *O. immunis* – Papershell Crayfish) ponds seine nets (Figure 25) are often used to capture crayfishes at which time sorting is manually undertaken (Figure 26) in order to select crayfishes of certain preferred "bait" sizes and soft shelled individuals which are the preferred prey items of many sport fishes such as smallmouth bass. However, active capture methods such as seines are usually ineffective in vegetation choked crayfish ponds (*Huner, 1988*).

FIGURE 25: *Using a seine net to collect (Orconectes immunis) Papershell Crayfish from a commercial production pond in Southern Ontario (photo by R. Taylor, courtesy of G. Watson).*

FIGURE 26: *Sorting tray used to select suitable (Orconectes immunis) Papershell Crayfish to be sold as baitfish (photo by R. Taylor, Courtesy of G. Watson).*

TRAPABILITY

Four combinations of physiochemical factors affect crayfish trapability in ponds (Huner, 1994). These factors are water temperature, moon phase, rain shower activity and cold fronts. In one investigation, catches of crayfishes increased as daily average temperatures increases to approximately 30°C (86°F). Morning and afternoon rain showers also increased catches, but catch declined with the approach of a full moon and with the passage of a cold front (Huner, 1990).

CRAYFISH ATTRACTANTS

OVERVIEW

Traditionally, when trapping crayfishes, baits used are generally comprised of cut fish. Baits most widely used as crayfish attractants in North America are traditionally inexpensive, bony, tough-fleshed fishes such as bony and oily herrings and shads (clupeids), suckers (catastomids) and carp (cyprinids). Cut fish is effective as crayfish bait but has several shortcomings. Natural baits are messy and inconvenient to store and require the use of freezers. Additionally, the manual cutting of fish is an unpleasant and time consuming task and, along with the discarding of old bait, can create potential health hazards associated with unsanitary conditions (*Huner, 1991, 1994*). Popular alternatives to cut fish include both canned and pellet formulations of inexpensive dog and cat food placed in meshed bags or small perforated containers (*Huner, 1990*).

COMMERCIAL CRAYFISH BAITS

The need for both inexpensive and mess-free crayfish attractants for the southern United State commercial crayfish industry has also led to the development of grain-based manufactured crayfish baits similar to low quality, commercial fish feeds (*Huner, 1990*). A number of companies now manufacture commercial crayfish baits that are easy to use. Manufactured crayfish baits take the form of compressed pellets of grain or seed products such as and including corn meal, rice bran, soybean meal, cottonseed meal, fish meal, additional chemical attractants, and material used to bind the formulation together (*Huner, 1994*). Manufactured baits are shelf stable, clean and readily available at a reasonable cost. The stability of manufacture baits can vary from a few hours to several days depending on the binder used and the feeding activity of the crayfishes. Pellets are round and have a diameter of 5-7.5 cm (1.9-2.9 in.) and are placed loose in the bottom of a trap. The North American baits are similar to low quality fish feeds in formulation (*Huner, 1991*). Protein levels within these formulations range from 15-25% (*Huner, 1994*).

BAIT USE RECOMMENDATIONS

Harvesting costs can account for a large proportion of costs in a given crayfish harvesting operation. Therefore it is prudent to use minimal quantities of bait. Research has shown that 110-125 g (3.9-4.4 oz.) of bait per trap is the most cost-effective quantity per set (*Huner, 1994*). Note that although high protein manufactured baits attract more crayfishes, they are not always the most cost-effective bait (*Huner, 1994*). Temperature has a major impact on the effectiveness of manufactured baits. At water temperatures below 20-25˚C (68-77˚F) natural baits and manufactured baits with high protein levels are more effective than baits with low protein levels. In addition, an equal combination of cut fish and manufactured bait is often more effective than either used separately (*Huner et al., 1989; Huner, 1994*). Conversely, at higher water temperatures, baits with low protein levels become equally effective as microbial activity and the subsequent degradation of organic material releases crayfish attractants from the products grain base (*Huner, 1994*). Finally, combinations of both manufactured and natural baits together are more effective than either used alone in waters below 20˚C (68˚) (*Huner, 1990, 1994*)

TRANSPORTATION AND HOLDING

TRANSPORTATION

Intermoult crayfishes can live out of water for some time as long as their bodies are damp, their gill chambers are wet, and their environment remains cool (Huner, 1997). Humidity should be high to prevent desiccation of the gills. Some species may live for as long as several months under these conditions. These physiological adaptations allow for the transport of crayfishes over long distances. As a result, widespread introductions of hardy species (e.g. *Orconectes rusticus* – Rusty Crayfish) have occurred well outside their native ranges in North America and elsewhere (Huner, 1997). Crayfishes should be transported under refrigerated conditions with temperatures in the 4-8˚C (39-46˚F) range (Huner, 1990). This temperature range reduces the metabolism of both crayfish and potentially harmful bacteria (Huner, 1988, 1990). Ice or "chemical" ices may be used to lower temperatures in transportation containers but live crayfishes should never be allowed to remain submerged in cold water for extended periods of time (Huner, 1991).

HOLDING SYSTEMS

In general, there are three types of systems used to hold crayfishes under artificial conditions. These are: (i) the “Batch” system, (ii) the “Flow-Through” system and (iii) the “Spray” system. Batch systems consist of crayfishes held in baskets or boxes suspended in tanks. Water is periodically drained and replaced. The Flow-Through system is similar to the Batch system in that crayfishes are held in baskets or boxes. However, in the Flow-Through system crayfishes are placed in a tank of continually flowing fresh water. Finally, in Spray systems, crayfishes are again placed in baskets or boxes, however, in this system a fine spray or mist of water is directed onto the crayfishes. This system is thought to be advantageous as minimal amounts of water are required for flushing and no aeration is required as crayfishes use atmospheric oxygen (*Huner, 1990*). Unlike the Spray system, the Batch system and Flow-Through system both require significant volumes of water to continually flush and aerate crayfishes (*Huner, 1990*).

WATER QUALITY

Water quality parameters suitable for the rearing and culture of freshwater crayfishes include the following:

ALKALINITY AND HARDNESS

Alkalinity represented as total as calcium carbonate should be greater than 50 mg/l (50 ppm); hardness (expressed as total as calcium carbonate) should be greater that 50 mg/l (50 ppm). (Also see Chapter 12: An Overview of Crayfishes – Crayfish Population Regulation: Calcium Availabilty.)

pH

Hydrogen ion concentration expressed as pH ranging between 6.5-9.0 are tolerated by crayfishes. However, pH values between 7.0-8.0 are preferable (*Huner and Barr 1991; Huner 1994*). (Also see Chapter 12: An Overview of Crayfish – Crayfishes Population Regulation: Low pH Environments.)

AMMONIA, CARBON DIOXIDE, HYDROGEN SULFIDE AND IRON

Both ammonia and carbon dioxide levels should remain under 5 mg/l (5 ppm). Concentrations of hydrogen sulfide should be undetectable. Iron (ferrous) should be less that 0.3 mg/l (0.3 ppm).

SALINITY

Crayfishes will tolerate salinities of 5 mg/l (5 ppm) but freshwater is always preferable (*Huner 1988, Huner, 1991; Huner, 1994*).

TEMPERATURE

Thermal minima and maxima are in the 2-34˚C (36-93˚F) range. Preferred temperatures range between 21-25˚C (70-77˚F). (Also see Chapter 12: An Overview of Crayfishes – Crayfish Population Regulation: Temperature.)

TURBIDITY (MURKINESS)

There are no recommendations for turbidity values as crayfishes do well at values of 400 NTU and higher (*Huner, 1990; 1994*).

OXYGEN

Oxygen is considered to be the principal water quality problem in crayfish ponds (*Huner, 1994*). Most crayfishes show obvious signs of stress at DO levels below 3 mg/l (3 ppm) and begin to die at concentrations below 1 mg/l (1 ppm). Low levels of oxygen are a result of high Biological Oxygen Demand (BOD) which arises as a result of the rapid decomposition of vegetation and organic detritus. (Also see Chapter 12: An Overview of Crayfish – Crayfish Population Regulation: Dissolved Oxygen.)

TOXIC SUBSTANCES

Crayfishes are sensitive to many pesticides and such contaminants can be toxic to crayfishes. Insecticides are generally more toxic than herbicides and fungicides. Combined effects of a mixture of pesticides can be more toxic that individual pesticides. Crayfish culturists should avoid using toxic chemicals in and around crayfish ponds and avoid the use of surface or sub-surface contaminated waters (*Huner, 1991; Huner, 1994*). Well water is recommended as a source of water to fill crayfish ponds as it is usually free from predators and competitors (e.g. fishes) and pollutants. However, well water may have toxic levels of dissolved iron and hydrogen sulfide and will normally have to be aerated to eliminate excess iron and hydrogen sulfide if present and to oxygenate it (*Huner, 1988, Huner, 1991, Huner, 1994*). Surface water is generally cheaper to obtain than well water but may not be available in sufficient quantities when needed. Aerators can serve to improve the quality of surface waters (*Huner, 1991*).

* *Note: Excellent crayfish production has been observed in ponds with almost 0 mg/l total hardness but alkalinity above 100 mg/l (100 ppm). In this situation crayfishes were able to obtain enough calcium from food and bottom sediments to sustain growth and reproduction (Huner, 1991; 1994). (Also see Chapter 12: An Overview of Crayfishes – Crayfish Population Regulation: Calcium Availability.)*

Contributors and Section References

CONTRIBUTORS

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10. Illustrated Guide to the Crayfishes of Ontario, 11. An Overview of Crayfishes, 12. Common Infectious Diseases, Parasites and Predators, and 13. Crayfish Aquaculture

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PREMEK HAMR

10. Illustrated Guide to the Crayfishes of Ontario, 11. An Overview of Crayfishes, 12. Common Infectious Diseases, Parasites and Predators, and 13. Crayfish Aquaculture

Dr. Premek Hamr is a teacher of Environmental Science at Upper Canada College in Toronto. He has been studying freshwater organisms over the past 20 years in both Canada and Australia. He obtained his Bachelor's degree in Environmental Biology at Concordia University, his Masters degree in Watershed Ecosystems at Trent University and his Doctorate in Zoology at the University of Tasmania. Over the years, his research has dealt with life history, reproductive biology, ecology, behaviour, distribution, taxonomy and conservation of aquatic invertebrates and fishes. He has appeared on Australian radio and television and has given numerous lectures as well as published a number of scientific and popular articles dealing with Canadian and Australian freshwater fauna.

ALETA KARSTAD

10. Illustrated Guide to the Crayfishes of Ontario

Born in 1951, Aleta grew up in Guelph, Ontario, but lived as a girl in Wisconsin and Georgia as her father studied wildlife pathology. Her formal art training was at Central Technical School, Toronto, where she studied watercolour under Doris McCarthy. In 1972 she began work in biological illustration at the National Museum of Canada. Aleta's easel paintings catch rhythm and movement in nature. She prefers to paint outdoors, to see and feel the depth and movement and the quality of time and place that she seeks to communicate through her art. Her mission is to teach people to love the land and its inhabitants.

Aleta's books, *Canadian Nature Notebook* (1979), *Wild Seasons Daybook* (1985), *North Moresby Wilderness* (1990) and *A Place to Walk* (1995), have been drawn from her illustrated natural history journals. Since 1995 she has been teaching her method of combining drawings, watercolours, and lettering on archival-quality materials to make a permanent record of a place and time.

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