

Biological Synopsis of the Chinese Mitten Crab (*Eriocheir sinensis*)

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2007

**Canadian Manuscript Report of
Fisheries and Aquatic Sciences 2812**

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CHINESE MITTEN CRAB (*Eriocheir sinensis*)**

by

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Cat. No. Fs 97-4/2812E ISSN 0706-6473

Correct citation for this publication:

Veilleux, E., and de Lafontaine, Y. 2007. Biological synopsis of the Chinese mitten crab (*Eriocheir sinensis*). Can. Manusc. Rep. Fish. Aquat. Sci. 2812: vi + 45p.

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ABSTRACT

Veilleux, E., and de Lafontaine, Y. 2007. Biological synopsis of the chinese mitten crab (*Eriocheir sinensis*). Can. Manusc. Rep. Fish. Aquat. Sci. 2812: vi + 45 p.

The Chinese mitten crab (*Eriocheir sinensis*) is an aquatic invader that could pose a potential threat to Canadian freshwater and brackish biological communities and ecosystems. The crab can cause bank erosion by intensive burrowing and disrupt fisheries by feeding on trapped fish and baits and by damaging nets. As a prerequisite for conducting a risk analysis of a potential invasion of Canadian waters by this species, this biological synopsis summarizes information on the species' description, distribution, biology and natural history, use by humans and impacts. The Chinese mitten crab is native to the Yellow Sea coast in China and Korea. The species was introduced in Germany in 1912 (Aller River). It subsequently established itself in Europe, spreading westward to Spain and eastward to Russia. In North America, the only established population so far is in San Francisco Bay, California, in the United States. Since the first capture in the Detroit River in Canada in 1965, at least 17 crab specimens have been caught in the Great Lakes. Ballast water discharges from ships are identified as the most probable vector for these introductions. In 2004, a first mention of the species was recorded in the St. Lawrence River in front of Québec City. Following the first record for the St. Lawrence River, six additional specimens were captured between Lake Saint-Pierre, in fresh water about 150 km upstream from Québec City, and La Pocatière in the estuary 110 km downstream from Québec City. Because of its catadromous life cycle, which requires saltwater for reproduction, the presence of the Chinese mitten crab in the St. Lawrence River and estuary is of great concern and deserves attention in future years.

RÉSUMÉ

Veilleux, E., and de Lafontaine, Y. 2007. Biological synopsis of the chinese mitten crab (*Eriocheir sinensis*). Can. Manusc. Rep. Fish. Aquat. Sci. 2812: vi + 45 p.

Le crabe chinois à mitaine (*Eriocheir sinensis*) est une espèce envahissante qui constitue une menace potentielle pour les communautés biologiques aquatiques canadiennes. Ce crabe se caractérise en outre par une intense activité de creusement pouvant causer une déstabilisation des berges et par une habitude à perturber les activités de pêche en s'alimentant sur les prises et les appâts et en causant des dommages aux engins de capture. Dans l'optique de réaliser une analyse du risque d'invasion causé par cette espèce au Canada, une synthèse des connaissances générales a été réalisée en prenant en considération la description de l'espèce, sa taxonomie, sa distribution globale, sa biologie, ses utilisations par l'humain et les impacts potentiels pouvant découler de son établissement. Le crabe chinois à mitaine est indigène des côtes chinoise et coréennes bordant la mer Jaune. En Europe, l'espèce a été introduite en 1912 dans la rivière Aller, en Allemagne, et s'est ensuite étendue vers l'Europe de l'ouest, où elle est maintenant bien établie jusqu'en Espagne et vers l'est jusqu'en Russie. En Amérique du Nord, la seule population établie se trouve dans la baie de San Francisco, en Californie aux États-Unis. En 1965, un premier crabe a été capturé dans la rivière Détroit en eaux canadiennes et au moins 17 spécimens ont été recensés dans les Grands Lacs depuis ce temps. Le délestage des eaux de lest des navires est identifié comme la cause la plus probable de ces introductions dans le Grands Lacs. En 2004, une première mention de cette espèce a été faite dans le fleuve Saint-Laurent, près de la ville de Québec. Six spécimens additionnels ont par la suite été capturés entre le lac Saint-Pierre, situé en eau douce environ 150 km en amont de la ville de Québec, et La Pocatière, à environ 110 km en aval, dans l'estuaire. Le crabe chinois à mitaine étant une espèce catadrome se reproduisant en eaux salées, sa présence dans le fleuve et l'estuaire du Saint-Laurent est grandement préoccupante et mérite une attention toute particulière dans les années à venir.

1. INTRODUCTION

Biological invasions into Canadian lands and waters, as elsewhere in the world, have negatively affected local biodiversity and the functioning of ecosystems (Claudi et al., 2002; Lodge et al., 2006). The Great Lakes-St. Lawrence basin is one of the most invaded freshwater ecosystems in the world, with more than 182 established non-indigenous species (de Lafontaine and Costan, 2002; Ricciardi, 2006). The Chinese mitten crab (*Eriocheir sinensis*) is listed among the “100 of the world’s worst alien invasive species” (ISSG, 2006), mainly because of its ability to spread rapidly into new habitat as happened in many European countries (Herborg et al., 2003, 2005) and in San Francisco Bay in the United States (Rudnick et al., 2003). When present in large densities, the crab can cause several inconveniences to human aquatic activities. In Germany and the United States, crabs have been reported to steal fish baits, to damage fishing nets and lower catches by fouling fixed fishing gear such as fyke nets, weirs and traps (Panning, 1938; CMCWG, 2003).

This highly invasive species was first reported in Canada in 1965 at Windsor in the Detroit River (Nepszy and Leach, 1973). Over the next forty years, the crab was reported at various locations in the Great Lakes, most often in Lake Erie (Tepolt et al., 2007). A Chinese mitten crab was collected for the first time across the river from Québec City at the downstream end of the St. Lawrence River in September 2004 (de Lafontaine, 2005). In 2005 and 2006, specimens were again reported in Lake Saint-Pierre and in the St. Lawrence estuary and others were also caught in the Great Lakes region.

These repeated observations have led to concerns that the species might establish itself in Canada. A biological synopsis of the Chinese mitten crab is therefore presented here as a prerequisite for a risk assessment of this non-indigenous species in Canadian aquatic systems.

1.1 NAME AND CLASSIFICATION

The taxonomic classification of the Chinese mitten crab was recently revised by Clark (2006), who demonstrated that the genus *Eriocheir* correctly belongs to the Varunidae and not to the Grapsidae as previously indicated. He also corrected the date of the designation of *E. sinensis* to 1853 (from 1854).

From the Integrated Taxonomic Information System (ITIS), 2007, and the Invasive Species Specialist Group (ISSG), 2006:

Kingdom: Animalia
Subphylum: Crustacea
Phylum: Arthropoda
Class: Malacostraca

Order: Decapoda
Family: Varunidae
Genus: *Eriocheir* (de Haan, 1835)
Species: *Eriocheir sinensis* (Edwards, 1853)
Other scientific name: *Eriochirus sinensis* (erroneous spelling of genus name)
(Edwards, 1853)
Common English name: Chinese mitten crab
Other English name: Chinese freshwater edible crab
Common French name: *crabe chinois à mitaine*
Other French name: *crabe poilu de Shangai*

1.2 SPECIES DESCRIPTION

The Chinese mitten crab is a decapod crustacean so named for its most conspicuous morphological characteristic, the dense patches of light brown setae on its white-tipped claws (Figure 1a). These hairy-like features give the crab the appearance of wearing furry mittens. These “mittens,” considered as a secondary sexual character, are overgrown on sexually mature male specimens but are also found on females and large juveniles (Rudnick et al., 2000). The two claws are approximately of equal size, with males having slightly longer claws than females of similar carapace width (Normant et al., 2007). The carapace of adult specimens can reach 80 mm in width, although some larger individuals up to 100 mm wide have occasionally been found (Rudnick et al., 2000; Veldhuizen, 2001). No major differences in size between sexes have been reported (Zhang et al., 2001). The four pairs of walking legs are usually twice as long as the carapace width, which makes this crab a very large one. In older juvenile and adult specimens, the distal segments of the walking legs bear short hair along the lateral margins. The carapace is nearly square-shaped in adults, being slightly wider than long. Four spines are evident on both sides of the lateral margin of the carapace and a frontal notch, flanked by two small spines, is located between the eyes (Figure 1a) (Rudnick et al., 2000). The color of the carapace varies from brownish-yellow, mostly in juvenile individuals, to greenish-brown in adult crabs and recently molted specimens (Hymanson et al., 1999). The differentiation between sexes is relatively simple. The males have a V-shaped abdomen with narrow abdominal flaps (Figure 1b) whereas females have large abdominal flaps that extend to the edge of the abdomen when fully mature (Rudnick et al., 2000).

1.3 TAXONOMY OF *ERIOCHEIR*

The taxonomy of mitten crabs (genus *Eriocheir*) is still under debate and the determination of its status has stimulated many recent genetic studies. In all, five different species have been classified by various authors and a sixth species, *E. ogasawaraensis*, was recently identified by Komai et al. (2006). All authors agree that the type species of the genus is *E. japonica* (de Haan, 1835),

sometimes designated as *E. japonicus*. The four other species are *E. sinensis* (Edwards, 1853), *E. hepuensis* (Dai, 1991), *E. formosa* (Chan, Hung and Yu, 1995) and *E. leptognatha* (Rathbun, 1913), sometimes designated as *E. leptognathus*.

Ng et al. (1999) have suggested grouping the five species into three genera: *Eriocheir* (*E. japonica*, *E. sinensis* and *E. hepuensis*); *Neoeriocheir* (*N. leptognatha*); and *Platyeriocheir* (*P. formosa*).

Conversely, Chu et al. (2003) have argued for maintaining the five species within the genus *Eriocheir*. They have shown that *E. japonica* and *E. hepuensis* are closely related to *E. sinensis*, both in morphological and genetic terms. Only a few characters are useful for differentiating these three species, such as the location of the vulvae in adult females, the shape of the protogastric crest and the size of the fourth spine on the lateral margin of the carapace (Chu et al., 2003).

Tang et al. (2003) have suggested, however, that the three species *E. japonica*, *E. sinensis* and *E. hepuensis* are conspecific and should be considered as three subspecies of *E. japonica*, respectively designated as *E. j. japonica*, *E. j. sinensis* and *E. j. hepuensis*. The two others species, *E. formosa* (Chan, Hung and Yu, 1995) and *E. leptognathus* (Rathbun, 1913), are genetically and morphologically more distant from the three first species, with *E. leptognathus* being the most genetically distant within the genus (Chu et al., 2003; Tang et al., 2003). The use of the genus *Neoeriocheir*, previously proposed by Ng et al. (1999), was supported by Tang et al. (2003), but these authors did not find solid evidence to support the existence of the genus *Platyeriocheir*.

All these studies reflect the existing confusion about the taxonomy of mitten crabs and show the necessity for further genetic and/or morphological studies to help clarify the exact taxonomic status of the Chinese mitten crab.

2. DISTRIBUTION

The Chinese mitten crab is found in the northern hemisphere only and is native to Asia; it was introduced into Europe and North America (Figure 2). Major established populations of the crab outside of its native range are distributed in Europe and on the west coast of the United States.

2.1 NATIVE DISTRIBUTION

The Chinese mitten crab is endemic to the Yellow Sea region bordering China and Korea, in Eastern Asia (Figure 2). Its native habitats are the coastal rivers and estuaries running into the sea from North Korea (approximately lat. 40°N latitude) to Hong Kong (approximately lat. 22°N) in the south of China

(Hymanson et al., 1999). The species is also present in South Korea and Japan and was introduced into Vietnam, extending its distribution in Asia. The Yangtze River is the largest river within its native range and specimens have been collected as far as 1400 km up in the river (Cohen and Weinstein, 2001). Most studies on the Chinese mitten crab in Asia have been conducted on the Yangtze River crab population (Hymanson et al., 1999).

2.2 INTRODUCED RANGE

2.2.1 Invasion into Europe and western Asia

The crab is well established in European countries bordering the North Sea, where it was first reported in the Aller River, a tributary of the Weser River in Germany, in 1912 (Panning, 1938) (Figure 3). In 1914, it was found in the Elbe River, only 60 km east of the Weser River. Once in the Elbe River, it reached the Baltic Sea, where it was first reported in 1926 (Panning, 1938; Herborg et al., 2003). In 1933, it was found throughout the Baltic Sea and was reported as far east as Vyborg in Russia and in Finland waters (Herborg et al., 2003).

To date, Chinese mitten crabs have been found all around the Baltic Sea in Denmark, Germany, Poland, Russia, Estonia, Finland and Sweden, although the species is usually less common along the north shore (Ojaveer et al., 2006). In 2003, adult crabs were found migrating down the Neva River at the east end of the Gulf of Finland (Baltic Sea) and, in 2005, specimens were collected in Russia in Lake Ladoga, which empties into the Neva River (Panov, 2006).

It is still uncertain as to whether the Chinese mitten crab can reproduce in the Baltic Sea and in the Gulf of Finland, because of the low salinity of these coastal seas (Anger, 1991). Migration of juveniles from the North Sea, either via the Kiel Canal or the Kattegat/Skagerrak region (more than 1500 km from the most northerly crab occurrence within the Baltic Sea) was hypothesized as the most probable scenario to explain the crab's presence and the population increase in the Baltic Sea (Ojaveer et al., 2006). Ship transport via ballast water discharge may also be a vector, as there are many ships transiting between the North Sea and the Baltic Sea every year (Pienimäki and Leppäkoski, 2004).

Between 1920 and 1940, the crab spread westward from Germany, successively invading Denmark, the Netherlands, Belgium and northern France (Kamps, 1937; Leloup, 1937; Panning, 1938; Hoeserlandt, 1945). Over time, the crab migrated up the Elbe River as far as Prague in the Czech Republic, 700 km from the North Sea (Cohen and Weinstein, 2001) and in the Oder River (Poland) up to Breslau, 464 km from the Baltic Sea (Herborg et al., 2003). It also invaded the Rhine River, migrating 512 km upstream from the river mouth in the Netherlands (Herborg et al., 2003). Specimens were first caught in the Loire River at Nantes (France) in 1954; some crabs were also caught during the same year near

Bordeaux, in the estuary of the Gironde (France). At that time, these two southernmost occurrences of the crab in France were thought to be the result of separate invasions (Herborg et al., 2003). Five years later, the species reached the Mediterranean coast via the Midi Canal, a 241-km artificial waterway between Toulouse and the Thau Lagoon near Sete in France, but this did not result in population establishment (Petit, 1960).

The Chinese mitten crab in the United Kingdom was first reported in the Thames River in 1935, but only became established in 1973 (Ingle, 1986; Rainbow et al., 2003). From that location, the crab spread to many other rivers in the United Kingdom (Herborg et al., 2005). In the late 1980s, crabs were found in the Tagus River in Portugal, where the species had become established by 1990 (Cabral and Costa, 1999). Since 1997, the crab has also established itself in the Guadalquivir estuary, near Seville's harbour in Spain (Cuesta et al., 2004). These last two records represent the southernmost occurrences to date of the species in Europe. Two Chinese mitten crabs were also collected in the Serbian section of the Danube River in June 1995 and November 2001, but evidence of established populations in that river has yet to be demonstrated (Paunovic et al., 2004). In May 2005, one individual was found in the Mediterranean Sea, in the central part of the Venice Lagoon in Italy (Mizzan, 2005). In the far northeastern part of Europe, Chinese mitten crabs are now regularly captured in the Archangel Bay of the White Sea in Russia (Berger and Naumov, 2002). Several European invasions have been characterized by a long lag phase where the occurrence of only a few crabs each year over an extended period preceded a sudden population explosion under favourable conditions, as observed in the Thames River (Herborg et al., 2003, 2005).

The crab is presently extending its range from Europe to West Asia via canals or new introductions. Frequent reports of crabs in the Ukrainian part of the Black Sea and in the adjacent Azov Sea are interpreted as confirmations of established populations in these waterbodies (Murina and Antonovsky, 2001; Gomoiu et al., 2002). In October 2002, a mitten crab specimen was captured in the Tazeh Bekandeh River (Caspian Sea) in Iran (Robbins et al., 2006) and, in June 2005, one individual was caught in the Shatt Al Basrah Canal flowing into the Persian Gulf in Iraq (Clark et al., 2006). The establishment at these two locations is not confirmed yet. Crabs in the White Sea, the Black Sea and the Caspian Sea are believed to have come from the Baltic Sea by active migration via canals and causeways. On the other hand, the occurrence of the crab in Iraq is thought to be the result of ballast water introduction.

2.2.2 Occurrence in the United States of America

The only confirmed established population of Chinese mitten crabs in North America is in the United States, especially in San Francisco Bay, California (Figure 4), where the first mention was made in 1992. By 1998, the population abundance had exploded in numbers and crabs were found throughout the bay.

During surveys conducted between 1998 and 2000, the catches of adult crabs reached between 100 000 and 800 000 individuals per year in different parts of the bay (Rudnick et al., 2003). San Francisco Bay is the only location along the United States west coast where *E. sinensis* has been caught so far. A single mitten crab specimen caught in the Columbia River (Oregon) in 1997 was identified as *E. japonica* (Jensen and Armstrong, 2004).

On the eastern seaboard, there is no established population of mitten crabs, but specimens were recently reported in Chesapeake Bay in Maryland. A specimen was first caught just outside the mouth of the Patapsco River in Baltimore's harbour in May 2005 (Ruiz et al., 2006). In June 2006, a second specimen was reported at the mouth of the same river (Ruiz et al., 2006). In late April and June 2006, two other specimens were reported respectively in the mouth of the Patuxent River and on Chesapeake Beach, both in Maryland. The identification of these last two crabs was not confirmed because specimens were captured and discarded by fishermen. The confusion with any other crab species in the region seems very unlikely, however, and the two specimens were considered to be Chinese mitten crabs. In May 2007, four specimens of Chinese mitten crab were caught in Delaware Bay and one crab was collected in the Hudson River, New York, in June 2007. In addition to these recent northern records, one specimen was also caught in March 1987 in the Mississippi River Delta in Louisiana (Center for Aquatic Resource Studies, 2005).

2.3 RECORDS IN CANADA

The first capture of a Chinese mitten crab in North America was recorded in Canada in 1965 when a specimen was found in the Detroit River at Windsor, Ontario, in the Great Lakes (Figure 5) (Nepszy and Leach, 1973). Since this capture took place only five years after the opening of the St. Lawrence Seaway, which gave larger transoceanic ships access to the Great Lakes, it was thus suggested that the species might have been introduced through the discharge of ship ballast waters (Nepszy and Leach, 1973). Since that first mention, several other records have been made in the Great Lakes–St. Lawrence watershed through the years (Table 1). Between 1973 and 1996, 11 sightings were reported, mostly from the Lake Erie, but the species never became established in the Great Lakes because the lakes are too far from the saltwater environments necessary for the crab's reproduction (Anger, 1991). Between 2004 and 2007, five specimens were caught in Lake Erie and two in Lake Superior at Thunder Bay, Ontario. During the past three years, crabs were also collected for the first time at various locations along the St. Lawrence River. In September 2004, a female specimen with a 46-mm wide carapace was first noted in Lévis across from Québec City (de Lafontaine, 2005). During the fall of 2004, a fisherman also indicated the capture of one crab specimen at Sainte-Angèle-de-Laval on the south shore of the river across from Trois-Rivières, but the specimen was not kept so that its identification could not be confirmed. However, the absence of

any other crab species in the freshwater section of the St. Lawrence River makes misidentification very unlikely. In September 2005, one male specimen (37.8 mm wide) was caught on the south shore of Lake Saint-Pierre (de Lafontaine, pers. comm.). In 2006, four additional specimens were again captured by commercial fishermen in the St. Lawrence River. Two males and one female were caught in commercial weirs used for eel fisheries near La Pocatière in the St. Lawrence estuary in July and September 2006. In October 2006, a large male with a 72.3-mm wide carapace was caught in a commercial fyke net on the south shore of Lake St-Pierre. So far, all captures in the St. Lawrence River and estuary were made along the south side of the river. Most captures throughout the Great Lakes–St. Lawrence watershed were made by commercial fishing gears, except for the two specimens collected from intake screens at the Ontario Power Generation’s Thunder Bay Generating Station on Mission Island. The finding of three specimens in the St. Lawrence estuary represented the first evidence of the crab occurrence in suitable reproductive brackish waters within the Great Lakes–St. Lawrence River basin.

2.4 POTENTIAL DISTRIBUTION IN CANADA

Herborg et al. (2007a) recently conducted modeling of the invasion of the Chinese mitten crab in North America by developing two niche models based on established mitten crab populations in China and Europe. The two models took into account the environmental requirements for the survival of the crab (mainly physico-chemical water properties) and the propagule pressure linked to ship ballast water discharge. The two models yielded very similar results when the reproductive needs, which included access to water salinity of greater than 15 PSU, were added to the models. Considering the maximum distance for upstream migration recorded so far (approximately 1260 km), the lower Great Lakes (Lake Erie and Lake Ontario) and the St. Lawrence River were identified as environmentally suitable for the establishment of Chinese mitten crab populations. With a more stringent dispersal distance (354 km), only the St. Lawrence River up to Montreal was at risk for establishment.

The invasion risk model identified the Atlantic provinces and, more specifically, the east and south shores of New Brunswick, the entire Nova Scotia coastline and the eastern shore of Newfoundland from Fogo Island to the south of the Avalon Peninsula as potential environmentally suitable regions for the establishment of the crab along the eastern Canadian seaboard. On the Pacific coast, the south coast of British Columbia was also identified as being at high risk for colonization and establishment. This study did not take into account either biotic interactions within the potential new habitats, such as the predation pressure, or the management of ship ballast water. The inclusion of additional habitat characteristics such as benthic substrate and vegetation cover would also improve the resolution of these models for predicting the potential geographic range for the establishment of the Chinese mitten crab populations in Canada.

2.5 POPULATION GENETICS

Genetic population studies have attempted to reconstruct the history of the invasion of the Chinese mitten crab in Europe and in North America. Sequence variation of the mitochondrial CO1 gene of crabs from China, Europe and America has led to the determination of seven different haplotypes (Table 2) (Hänfling et al., 2002; Tepolt et al., 2007). The seven haplotypes were closely related and differed from one another by a few mutations only. This low sequence variation suggested that the crab populations analyzed had diverged only recently, a suggestion that was consistent with the very young age of the approximately 100-year-old European population and the approximately 15-year-old San Francisco Bay population (Hänfling et al., 2002). The genetic diversity and the within-sample gene diversity were higher in the native population than in the recently established populations (Hänfling et al., 2002). This situation clearly indicates an erosion of the genetic diversity after the initial founder event. The somewhat higher genetic diversity observed in European populations may result from a single introduction event of a large number of crabs or from successive invasion events over time (Hänfling et al., 2002).

In their study, Hänfling et al. (2002) observed that the ES4 haplotype occurred at moderate frequencies (20–33 %) in Europe but was the only one found in San Francisco Bay in the United States (Table 2). This haplotype was not found, however, in any of the 22 crab samples from China (Hänfling et al., 2002). Without excluding the possibility that the ES4 haplotype may indeed be present at low frequency in the native populations in China, these results strongly suggested that the European population was probably the source of invasion of the Chinese mitten crab in San Francisco Bay. The presence of only one haplotype also suggested that the establishment of the North American population probably resulted from a single transfer event (Hänfling et al., 2002). Despite the low number of analyses performed so far ($n = 9$, Table 2), specimens from the Great Lakes and the St. Lawrence River belonged to three different haplotypes (ES1, ES4 and ES5), which are the most frequently reported in Europe. This allowed Tepolt et al., (2007) to suggest that the European *E. sinensis* population may be acting as a stepping stone to potential invasion of the Great Lakes–St. Lawrence River system. An introduction from China cannot be totally ruled out, however.

Using microsatellite markers, Herborg et al. (2007b) investigated the genetic structure and the migration pattern of the Chinese mitten crab populations in Europe. Their results corroborated those of Hänfling et al. (2002) by revealing a lower genetic diversity within the European population compared with the native one. Moreover, they showed that a homogenization of genes is now occurring in Europe owing to a relatively high gene flow between the different river systems (Herborg et al., 2007b). The researchers concluded that human-mediated transport (i.e. shipping) explained genetic variation better than any isolation by distance effect within the European populations which indicated that transfer by

ships is still a significant factor for the dispersal of mitten crabs between European ports.

2.6 PATHWAYS OF INTRODUCTION AND TRANSFER

It is now largely accepted that the worldwide spread of the Chinese mitten crab was due to human-mediated activities and not the result of natural causes (Cohen and Carlton, 1997). These authors identified 10 pathways (intentional and unintentional) that would explain the introduction and transfer of crab around the world:

- dispersal of larvae by currents
- passive dispersal of adults or juveniles on floating material
- transport of adults or juveniles by ship fouling
- transport of adults or juveniles in cargo
- transport of adults or juveniles on semi-submersible drilling platforms, barges and other long-distance slow-moving vessels
- transport of larvae or juveniles in ballast water
- transport of adults or juveniles in fisheries products
- transport of larvae in water with shipments of live fish
- escape or release from research, public, or private aquaria
- intentional transfer to develop a food resource

Among all these vectors, two were considered to be the most likely pathways: the active transport and voluntary release of mitten crabs into new habitats to provide a new human food source, and the accidental release of crabs via ship ballast water discharge (Cohen and Carlton, 1997).

In China, *E. sinensis* is considered a delicacy and supports an important aquaculture industry (Hymanson et al., 1999). Based on genetic analyses, the European origin of the San Francisco Bay crab population would have most likely resulted from the deliberate transport and introduction of live specimens to purposely establish food fisheries on the west coast of the United States (Cohen and Carlton, 1997; Hänfling et al., 2002). The deliberate introduction and transport of live Chinese mitten crabs for the food industry is now legally forbidden in Canada and United States.

The most probable unintentional vector for the introduction and transfer of the Chinese mitten crab is the transport by ship ballast waters. Presumably the uptake of pelagic larval stages would be responsible for the spread of the species via ballast water (Cohen and Carlton, 1997). In fact, the Chinese mitten crab was one of the first species reported in ballast tanks and was used as a first piece of evidence for the transport of living aquatic invasive species in ballast water (Carlton, 1985). In northern Europe, ship traffic from China headed for Hamburg (Elbe River) and Bremen (Weser River) has been frequent since the end of the 19th century, which may have very likely contributed to a founder specimens

introduction via incoming ships from China (Herborg et al., 2003). The presence of the crab in southern France probably arose through shipping activities (Herborg et al., 2003).

The introduction of the crab into the Great Lakes would result from the discharge of ballast water also. This is supported by the fact that most (approximately 88 %) of the international vessels entering the Great Lakes between 1983 and 1998 were from European ports (Grigorovich et al., 2003). Moreover, nearly 50 % of vessels entering Canadian waters since 1978 have come from European countries where the Chinese mitten crab was already well established and abundant (de Lafontaine et al., 2006).

Once Chinese mitten crabs have been introduced into a new habitat and are established, they can invade and colonize nearby water systems either by larval transport or migration by juveniles. Upon hatching in brackish waters, crab larval stages may drift considerably along coastal areas before settling into new habitats. Metamorphosed juveniles are capable of long upstream active migration that may introduce the crab into new freshwater systems adjacent to established population regions (Herborg et al., 2005). This natural drift pathway is believed to be responsible of the large spread of *E. sinensis* in northern Europe throughout the 20th century.

3. BIOLOGY AND NATURAL HISTORY

3.1 LIFE CYCLE

The Chinese mitten crab is an euryhaline species characterized by a catadromous life cycle. It spends most of its life in fresh or brackish waters. Mature adults migrate downstream during the fall to reproduce in brackish or salt waters (Figure 6). Both males and females are thought to die following reproduction (Panning, 1938). Females brood the eggs and, upon hatching, larvae are planktonic for one to two months. During this marine free-swimming phase, larvae pass through a series of developmental stages: a brief non-feeding pre-zoea stage, five zoea stages and one megalopea stage (Figure 7) (Anger, 1991; Montú et al., 1996). The morphology of the different larval stages from the pre-zoea to the first young crab stage has been extensively described by Montú et al. (1996). Under harsh environmental conditions such as low temperatures (below 15°C) in combination with low salinity (under 15 PSU), a sixth zoea stage and a second megalopea stage may be occasionally observed (Anger, 1991; Montú et al. 1996). Following the megalopal stage, the larvae metamorphose into juvenile crabs that settle to the bottom, usually in late summer or early fall (Rudnick et al., 2005a). The onset of this benthic life for the young crabs corresponds to the beginning of the active upstream migration into rivers to complete the life cycle in fresh water.

3.2 AGE AND GROWTH

The Chinese mitten crab can live between one and five years, depending on location. This variability in longevity is apparently related to the time needed to reach maturity and reproductive activity, since the crab is believed to spawn only once and die after reproduction (Panning, 1938). Shorter life spans of between one and three years were reported in aquaculture populations in the south of China (Zhang et al., 2001). In northern Europe, where the climate is colder, the time to maturity varies between four and five years (Gollasch, 1999), while in the warmer waters of San Francisco Bay, the majority of spawning crabs are at least three years old (Rudnick et al., 2005a). This geographic variation in age at maturity suggested that the achievement of maturity can be strongly dependant upon environmental conditions (Rudnick et al., 2005a).

Using crabs from the Elbe River in Germany in controlled laboratory experiments, Anger (1991) demonstrated that the developmental duration of all planktonic larval stages varies with water temperature (from 6 to 18°C) and salinity (from 10 to 32 PSU). He also observed that development from hatching to settlement of juveniles was successful at temperatures above 12°C only and that no survival of the first zoea stage occurred below 9°C. The time to complete the larval period and metamorphose into the juvenile stage ranged from 45 to 93 days, taking 90 days at 12°C (Anger, 1991; Montú et al., 1996; Rudnick et al., 2005a). Similar studies conducted on other crab populations would be useful to confirm the universality of these results.

In China, the crab was shown to molt between 10 and 12 times during the first year and between 3 and 8 times during the second year (Hymanson et al., 1999). The number of molts continued to decrease in subsequent years. In northern Europe, where waters are colder, the crabs shed 6 to 8 times during their first year, 4 to 5 times the second year, and 2 to 3 times during the third year (Panning, 1938). The growth rate of mitten crabs appears to be inversely related to their size and to be mainly affected by food availability and water temperature. Consequently, the growth rate usually increases during spring and summer and decreases during winter. According to Panning (1938), the annual growth rate of mitten crabs in northern Europe would correspond to an increase of the carapace length of around 12 mm per year. In rearing conditions, the growth of juveniles was stopped below 7°C and above 30°C, whilst the optimal temperature ranged between 20 and 30°C (Hymanson et al., 1999). When optimal environmental conditions are met, the mitten crab cans double its weight at each molt during its first year of life (Hymanson et al., 1999).

3.3 REPRODUCTION

Although the Chinese mitten crab spends most of its life in freshwater, it needs saltwater to reproduce. The reproduction involves a succession of events

occurring at various times of the year and at different water salinities (Figure 8). The development of gonads seems to be quite variable. It generally occurs during the downstream migration but can also begin in freshwater before the onset of the migration (Panning, 1938; Rudnick et al., 2005a). Factors stimulating the gonad maturation are not yet fully understood. Some authors have suggested that it could be a response to cyclical environmental conditions, such as decreasing day length following the summer solstice or higher water flow and lower water temperature following some heavy rain period (Toste, 2001 cited in Rudnick et al., 2005a). The development of sexual characters would be also linked to specimen size as there are no reports of reproductive mitten crabs below 30 mm. So far, the smallest reproductive crabs observed in various populations ranged between 30 and 42 mm (Jin et al., 2001; Rudnick et al., 2000; 2003).

Mating is believed to occur in brackish waters and eggs are laid generally within 24 hours after mating (Panning, 1938). Once spawned, the eggs are attached to small hairs on the pleopods under the abdominal flaps of the female with a cement-like substance (Panning, 1938). This cement-like substance hardens with the salinity of the water, explaining that mating and egg release is successful in brackish environments with salinity generally greater than 15 PSU. Ovigerous females can brood between 250 000 to 1 million eggs (Cohen and Carlton, 1997). Mating usually takes place during late-fall and winter and varies little between geographic regions. It occurs in November–March in Chinese rivers (Zhang et al., 2001), from October to January in the Elbe River in Germany (Panning, 1938) and from October to February in the United Kingdom (Herborg et al., 2006). In the San Francisco Bay estuary, the majority of ovigerous females are usually caught between November and March, with a small proportion between April and June (Rudnick et al., 2003). In the Thames River, mating was found to be synchronized with the neap-spring lunar cycle peaking at full or new moon (Herborg et al., 2006). Presumably, this may increase larval retention in relation to the neap-spring tidal cycle in estuaries.

The hatching period is likely to extend over several months, depending of the environmental conditions (Anger, 1991; Rudnick et al., 2003; 2005a). In the cold waters of northern Europe, the development of embryos may be slowed down so that ovigerous females remain in deep waters throughout the winter and return to the estuaries during spring when the eggs hatch (Ingle, 1986). In northwestern Germany, larvae normally hatch between March and July, but the hatching season may end in May or June during years with warmer springs (Panning, 1938).

3.4 PHYSIOLOGICAL TOLERANCES AND REQUIREMENTS

Because of its catadromous life cycle and its origin in temperate to subtropical countries, the Chinese mitten crab can tolerate a broad range of water temperatures and salinities. This physiological tolerance varies at different

developmental stages but, overall, the adult crab can survive at water temperatures ranging from near 4° to 31–32°C and at salinities varying from 0 to 35 PSU (Cohen and Weinstein, 2001). The species has become abundant in river systems with winter estuary temperatures as low as 5°C and adjacent sea surface water temperatures below 0°C (Cohen and Weinstein, 2001).

Hatching and larval development represent the critical stages for species survival and are strongly dependant upon water temperature and salinity in estuaries. Temperatures between 15 and 25°C during spring and summer are necessary to allow normal hatching and development of larvae (Cohen and Weinstein, 2001). Anger (1991) demonstrated that an increase in water temperature can lead not only to higher larval survival but also to a higher range of salinity tolerance by the larvae. Results from these experiments indicated that, at 12°C, larval survival was higher at 25 PSU than at 20 PSU, and was null at 10 PSU (Anger, 1991). The same experiment revealed that the salinity tolerance varied between the different larval stages, where early (Zoea I) and final (Megalopa) larval stages were more tolerant to lower salinity (as low as 10 PSU at 15°C). At 18°C, survival of early larval stages was highest at 15 PSU, and the survival of later larval stages was optimal in seawater (32 PSU). The megalopal stage exhibits an increased tolerance to low salinity as compared to previous zoeal stages. The capture of megalopea in both estuarine water and freshwater suggests that metamorphosis of the mitten crab is possible over a wide range of salinities. In the laboratory, larvae were unable to survive at temperatures below 9°C, irrespective of the water salinity (Anger, 1991).

All these laboratory results did not, however, correspond to field observations in terms of the present range of distribution of the mitten crab and the time of larval hatching in northern Europe (Anger, 1991; Cohen and Weinstein, 2001). The differences between laboratory observations of the temperature tolerance of the crab and its observed geographic distribution, particularly at high latitudes such as northern Europe and the White Sea, would require further experiments for better understanding of the relative importance of environmental parameters such as water temperature, salinity, freshwater discharge, day length or other combinations of parameters in natural condition. With respect to other chemical requirements such as calcium or other specific compounds, no such information was found in the literature.

Mitten crabs, both juveniles and adults, can survive for a relatively long time out of water (Velduizen and Stanish, 1999). Crabs can survive up to 35 days in wet meadows (Nepszy and Leach, 1973) and at least 10 days in their burrows during a drought (Velduizen and Stanish, 1999).

In terms of habitat quality, the Chinese mitten crab could survive in highly modified habitats and even in polluted waters (Hoestlandt, 1945; Ingle, 1986; Rudnick et al., 2003). It was suggested that the crab could take advantage of water pollution because an increase in water pollution has been linked to a

decrease in the abundance of fish preying upon the crab (Ingle, 1986). Conversely, it has been observed that in some rivers such as the Seine in France that the Chinese mitten crab population decreased following an increase in water pollution and later increased when water quality improved (Gollasch, 1999; Hymanson et al., 1999). Although further research studies would be useful to identify the mechanisms and the possible effects of water pollution on the population dynamics of the Chinese mitten crab, it seems that the species is relatively tolerant to poor water quality and polluted environments in some areas.

A 15-year study of the distribution and abundance of the crab in the Thames estuary in England revealed that the recruitment of the Chinese mitten crab may be linked to freshwater flow (Attrill and Thomas, 1996). Results showed that an increase in crab abundance during 1992–1993 did coincide with an overall decrease in the water flow following a drought in 1989. The maximum water velocity that the crab can sustain during its upstream migration is unknown, but field observations have revealed that water currents of up to 1.5 m/s would not counteract nor limit the upstream movement (Cohen and Weinstein, 2001). Human infrastructures and natural barriers, such as dams or falls, may also constitute physical limitations for the upstream migration and the establishment of very large populations. In China, 6 m high vertical barriers were shown to stop most crabs (Cohen and Weinstein, 2001). On the other hand, crabs use locks and fish ladders to move upstream and are frequently observed circumventing obstacles by walking over land (Panning, 1938; Petit, 1960; Cohen and Weinstein, 2001).

The St. Lawrence River is the thirteenth largest river system in the world, with a 1,610,000 km² watershed (St. Lawrence Center, 1996). The river is 650 km long between the outlet of Lake Ontario and Tadoussac at the mouth of the Saguenay River, and has a mean annual discharge of 12,600 m³/s at Québec City. Summer water temperature in St. Lawrence River and estuary varies largely between locations. In the freshwater section, it can reach up to 30°C in the nearshore zone (de Lafontaine et al., 2007). At Rimouski on the south shore of the lower estuary, maximum water temperature in mid-July rarely exceeds 14°C and does not last long (Sinclair, 1978; de Lafontaine et al., 1984). The risk model developed by Herborg et al. (2007a) would predict the establishment of the mitten crab in the St. Lawrence River system. However, the survival and the development of crab larvae in the St. Lawrence estuary and along the Gaspé coast remain uncertain due to the cold water temperatures prevailing all year round along that coast.

3.5 BEHAVIOR AND MOVEMENTS

The catadromous migration pattern of the Chinese mitten crab is certainly one of its most conspicuous behavioural characteristics. The downstream migration of adults occurs worldwide (in the northern hemisphere) during the fall, peaking

during September to October, and could be related with the decrease in day length (Veldhuizen and Stanish, 1999; Rudnick et al., 2005a). This corresponds to the time of the year when crabs are more often captured in fishing gears or are found in water supplies clogging screens, pipes and valves. During the fall of 1998, up to 50 000 crabs per day were counted at the water facilities in Tracy, California (Veldhuizen and Fost, 2001). In this respect, it is worth mentioning that almost all the reports of Chinese mitten crabs in the Great Lakes and St. Lawrence River as well as those in Chesapeake Bay were made in connection with commercial fishing activities and water pumping stations.

The estimated downstream migration speed is between 8 and 12 km per day (Panning, 1938). Usually, adult males migrate earlier than females and this chronological pattern was observed both in northern Europe and in San Francisco Bay (Panning, 1938; Ingle, 1986; Rudnick et al., 2000). Daily patterns of activities seem to vary during the life cycle of the crab. During their downstream migration to the southern delta (San Francisco Bay, California), crabs were more active during the late evening and the early morning hours (Rudnick et al., 2003). This is consistent with Gollasch (1999) and Panning (1938), who suggested that the crab is predominantly active at night. However, a study conducted in San Francisco Bay showed non-migratory crabs to be very active during the day, foraging and defending their burrows (Rudnick et al., 2000).

Based on the salinity and temperature tolerance values for the various life stages, Anger (1991) established a model of migration during the reproduction of *E. sinensis* (Figure 9). This model predicts that the hatching of larvae and the development of the first two larval stages would take place in the lower estuary, at salinities of between 10 and 25 PSU. Larvae at these early stages are likely to be transported by surface currents having a net direction out of the estuary. This agrees with field observations that early zoea larvae were largely found near the surface water (Forward and Buswell, 1989). The development of late zoea stages (from Zoea III to Zoea V) would take place in more saline coastal waters. The metamorphosis from zoea to megalopae leads to a benthic behaviour and to settlement of young crabs on the sea floor. Megalopae and early crab stages can be thus transported toward the coast and inner estuaries by onshore, near bottom, tidal currents. These developmental changes in larval behaviour and salinity tolerance may constitute a mechanism for estuarine retention of the species, by preventing larvae from being washed out of the estuary and by facilitating the return of crabs to freshwater habitats where they complete their life cycle (Anger, 1991). After metamorphosis, young crabs start their active upstream migration into rivers. Depending on the location, they can move over very large distances (up to 1000 km) during their growing phase and some specimens have collected quite far from their saltwater hatching habitats (Table 3).

Juvenile crabs are known for their important burrowing activity (Rudnick et al., 2005b). Within the intertidal zone, they can burrow themselves in soft-sediment banks mainly composed of sand and silt. Presumably, this would be a refuge against predation or protection from desiccation at low tide (Ingle, 1986; Rudnick et al., 2005b). In the South Bay tributaries of San Francisco Bay, burrow density was as high as 21 to 39 burrows/m² which, given the occupancy rates of mitten crab burrows, yielded crab density estimates of 19 individuals/m² in 1999 (Rudnick et al., 2003).

The shapes of burrows were variable, ranging from simple tube-shaped tunnels with only one terminal chamber and one entrance to complex burrows with multiple tunnels, entrances, bifurcations and terminal chambers (Rudnick et al., 2005b). Burrows were generally characterized by a downward slope from the entrance to the terminal chamber, allowing water to be retained in the terminal chambers at low tide. Burrows can be easily located by their low and wide entrances. The complex morphology of the burrows suggested that they are probably kept and reused over time by successive year classes of crabs (Rudnick et al., 2005b).

3.6 HABITATS

Estuaries supporting large mitten crab populations are all characterized by a large area of brackish waters for embryonic and larval development, and a large area of shallow productive waters for the growth of juveniles (Cohen and Weinstein, 2001). This describes well the Yangtze River, one of the major rivers used by mitten crab in its native China, which is considered an ideal habitat for mitten crab characterized by a long freshwater drainage with warm, slow moving water and a large estuary (Hymanson et al., 1999).

Throughout its life, the Chinese mitten crab will occupy different ecosystems depending on its life stage. Adult crabs are found in fresh, brackish and salt waters, but oviparous females are normally found in greatest number in saltwater (Rudnick et al., 2003). Larval stages are found in the open water of bays and estuaries. Juvenile crabs are uncommon in open water but are found in tidal tributaries within a few kilometres of open water and in freshwater (Rudnick et al., 2003). Around the world, the highest densities of crabs are principally found within estuaries and the lower part of rivers (Cohen and Weinstein, 2001; Rudnick et al., 2003). Fast-flowing cold water rivers are generally considered less suitable habitats for the species. In San Francisco Bay, individuals were also found in less ideal habitats such as concrete-lined channels, probably as a result of some density-dependent effect caused by the large population size (Rudnick et al., 2000).

In the tidal zone of San Francisco Bay, juvenile mitten crabs were mainly found in low salinity areas (less than or equal to 3 PSU) with steep clay banks lined with

cattails (*Typha* sp.) (Rudnick et al., 2000). Field observations revealed that crabs in the tidal zones prefer to make their burrows in steeper sloped banks (greater than 35°) as opposed to nearly flat banks (5°), and to select for fine sediment substrates such as silt and clay, in preference to coarser sediments such as gravel (Rudnick et al., 2003; 2005a). In freshwater habitats, juveniles were generally observed in shallow areas with slow moving water near deep pools with emergent macrophytes (Nepszy and Leach, 1973; Hymanson et al., 1999; Rudnick et al., 2000). Juveniles were also observed upstream from riffles but not in the riffle zone itself (Rudnick et al., 2000).

3.7 FEEDING AND DIET

The Chinese mitten crab is omnivorous and opportunistic in terms of its diet, being able to eat whatever it can get (Panning, 1938; Hymanson et al., 1999; Rudnick et al., 2000). Its feeding habits and its diet do shift during its life cycle (Hymanson et al., 1999; Rudnick and Resh, 2005).

The larvae feed on phytoplankton and zooplankton, while the diet of newly settled juveniles consists mostly of aquatic plants. As they grow, crabs become more carnivorous (Hymanson et al., 1999). A feeding study on crabs from San Francisco Bay using stable isotopes, mesocosms experiments and gut content analysis demonstrated that algae and detritus were the major components of the species' diet (Rudnick and Resh, 2005). This was consistent with previous gut content analyses showing that freshwater crabs relied mostly on the plant kingdom for food (Panning, 1938). The major vegetation types consumed were filamentous algae, *Potamogeton*, *Elodea* and *Lemna* (Veldhuizen and Stanish, 1999).

To harden its shell, the crab needs lime, which can be obtained only by consuming animals. Invertebrate parts and debris were identified in only 2 % of the stomach content of juvenile crabs with a diet mainly composed of detritus (Rudnick et al., 2000). Although the prevalence of invertebrates is generally low compared to other sources of nutrients, crabs in their intertidal estuarine and freshwater habitats feed preferably on algal-associated invertebrates such as chironomids and on shallow-dwelling invertebrates such as gastropods and burrowing amphipod (*Corophium*), as opposed to deeper sediment-dwelling species such as oligochaetes (Rudnick and Resh, 2005). Earlier European observations indicated also that the crab can feed on benthic invertebrates including worms (especially *Tubifex*), clams, snails, freshwater shrimps (*Gammarus*, *Crangon*), inferior crustaceans (*Daphnia*), water insects and insect larvae (Panning, 1938).

Crabs were reported to feed on dead fish and occasionally on injured or moribund fishes (Panning, 1938; Rudnick et al., 2000). They feed also on fish caught in nets or traps as well as on bait, which can negatively affect commercial fisheries (Panning, 1938; Gollasch, 1999). Although it has been suggested that crabs could feed on live fish, laboratory experiments showed that putting crabs

and healthy perch together in an aquarium did not result in attacks or the consumption of live fish (Panning, 1938). Rudnick et al. (2000) also kept mitten crabs and small fish together in an aquarium for several weeks without observing any predation behaviour. Crabs can however prey upon fish eggs laid on the bottom of rivers (Rainbow et al., 2003).

3.8 INTERSPECIFIC INTERACTIONS

The Chinese mitten crab is a large and aggressive crab that could represent an important predator for many taxa listed in the previous section. It could also compete for food with native crustaceans, as other crabs species or crayfish with opportunistic and omnivorous diets (Rudnick et al., 2000). Mitten crabs and crayfish (*Procambarus clarkii*) were observed feeding simultaneously on dead fish. In such situations, crayfish backed away almost each time crabs approached to feed on the same section of the carcass. Conversely, crabs would not retreat when crayfish approached the fish. This suggested that mitten crabs exhibit dominance over crayfish and may become a real competitor for food, particularly when the food supply is scarce. Rudnick et al. (2000) studied the interaction between the Chinese mitten crab and the signal crayfish (*Pacifasticus leniusculus*). They observed no predation by either species on the other, but some aggressive behaviours from the Chinese mitten crab were recorded, particularly in the presence of shelter. The competitive interactions between crabs and crayfish seem however to have minimal (or negligible) effects on crayfish abundance, as indicated by the lack of correlation between the presence of *E. sinensis* and the red swamp crayfish (*Procambarus clarkii*) on favourable sites for both species in San Francisco Bay (Rudnick et al., 2000). In laboratory conditions, mitten crab juveniles can successfully exclude similar sized green crabs (*Carcinus maenas*) from shelters (Gilbey et al., 2007).

Little is known about the predators of the Chinese mitten crab. It was suggested that many fish species including pike (*Esox* sp.), eels (*Anguilla* sp.), brown trout (*Salmo trutta*), sturgeon (*Acipenser* sp.), striped bass (*Morone saxatilis*) and channel catfish (*Ictalurus punctatus*) could prey upon the crab. Other aquatic-related animals such as bullfrogs, raccoons, river otters, wading birds and humans may also be counted among the potential predators of the mitten crab (Hymanson et al., 1999; Veldhuizen and Stanish, 1999; Veldhuizen and Hieb, 1998 cited in Hanson and Sytsma, 2005).

3.9 PARASITIC INFECTIONS AND DISEASES

The Chinese mitten crab, like other species of the genus *Eriocheir*, is a secondary intermediate host of the oriental lung fluke, *Paragonimus westermani* (Cohen, 2003). Mammals, including humans, are the final host for this parasitic trematode. Humans can be contaminated when ingesting raw or inadequately cooked crab. Symptoms of the infection are typically tuberculosis-like. No

transmission to humans has been reported so far in North America or in Europe. While research done on more than 13 000 crab specimens from San Francisco Bay did not reveal the presence of the fluke in this population, the risk of future parasite infection still persists. To complete its life cycle, the oriental lung fluke requires snails of the family Thiaridae as second intermediate hosts. The Thiaridae include mostly circumtropical warm-water species that are not currently found in northern Europe or North America. Given the absence of Thiarid snails in northern Europe, in the northern American states and in Canadian aquatic systems, the lung fluke life cycle could not be theoretically completed in those waters, therefore reducing the risk of human infection. No evidence of lung fluke or other exotic parasite was found in a crab specimen caught in the St. Lawrence River in 2006. (D. Marcogliese and A. Gendron, Environment Canada, Montréal, pers. comm.).

Normant et al. (2007) showed that numerous invertebrate epibionts (mainly nematodes, bivalves and crustaceans) inhabit the dense mussels covering the claws. The mitten crab has also been found to carry the North American crayfish plague fungus (Benisch, 1940). These epibionts and parasitic infections could possibly be transported over long distances either by migration or by import of live adult crabs for food.

4. HUMAN USES

4.1 USES AS HUMAN FOOD

The Chinese mitten crab is a traditional food source in China, where it supports an important aquaculture industry yielding high annual production (200 000 tons in 2000 (Chen and Zhang, 2006)), worth approximately \$1.25 billion (Hymanson et al., 1999). The reproductive tissues are the most delectable part of the crab, although the muscles are also consumed. The preferred crabs are those captured during the fall, as they have full gonads prior to reproduction and stored energy for the coming winter (Hymanson et al., 1999).

The importation of eggs or live specimens of any species of mitten crab (genus *Eriocheir*) is currently illegal in Canada under the *Guide to Canadian Regulatory Requirements and Examination Procedures for Imported Fish* provided by the Canadian Food Inspection Agency (2006). It is also illegal to import into the United States under the federal *Lacey Act* in 1989. However, Cohen and Carlton (1997) recorded 16 cases of interception of live mitten crabs at the San Francisco international airport between 1989 and 1995, with 10 to 50 specimens taken in each case. The transport and rearing of mitten crabs (from established populations) for any use has been prohibited in California to reduce the risk of species spread into uncolonized rivers and to prevent the development of a market for it. The transport and keeping of live mitten crabs (and other aquatic resources) is not be authorized in many provinces of Canada.

The increasing abundance of mitten crabs in the United Kingdom, Germany and the United States in San Francisco Bay has recently led some people to propose the development of a commercial fishery and export to China as a culling strategy (Gollasch, 1999; Rudnick et al., 2000; Rainbow et al., 2003).

4.2 OTHER USES

Crab specimens have been used as bait for eel fishing, food for cattle and chicken, fertilizer for agriculture and material for the production of cosmetics (Gollasch, 1999; ISSG, 2006).

5. IMPACTS ASSOCIATED WITH INTRODUCTIONS

Although several potential impacts associated with the introduction and establishment of the Chinese mitten crab into new environments have been hypothesized, only a few cases have been really documented for European and American waters.

5.1 ECOLOGICAL IMPACTS

The crab can have ecological impacts on native species, either through competition for food or habitat or through predation, but field observations of such interspecific interactions remain relatively scarce so far. Crayfish species, particularly rare or endangered ones, could be negatively affected by very abundant crab populations because of common freshwater habitat and diet shared by both species (Veldhuizen and Stanish, 1999; Rudnick et al., 2000). The predation on fish eggs might be of concern (CMCWG, 2003); however, quantitative assessments of the potential impacts on fish population dynamics are lacking. Given that fish material made up only 2.4 % of crab gut contents analyzed in Germany (Thiel, 1938 cited in Panning, 1938), the impact on adult fish populations would presumably be low.

The life cycle of the crab implies that adults actively migrate out of freshwater systems to reproduce and die in estuaries. Rudnick and Resh (2005) indicated that this may constitute a substantial vehicle for exporting biomass out of the freshwater ecosystems, which may impact the food web, particularly when in the presence of very large densities of crabs. These authors further argued that the crabs feed on and transform organic detritus, making it less available to other aquatic organisms, which can impair the freshwater benthic food webs.

5.2 IMPACTS ON RIVER INTEGRITY

The burrowing activity of crab juveniles might affect the integrity of river and lake shorelines by weakening banks and destroying bank vegetation, leading to erosion and bank collapse (Panning, 1938). The burrowing activity of the crab might also threaten unprotected human earthworks such as digs and levees (Rudnick et al., 2000). Rudnick et al. (2005b) calculated that the loss of sediments from crab burrowing activities averaged 3 % per 0.5 m³ of bank in tributaries of South San Francisco Bay, where the density of crab was very high (> 11 crabs/m²). Steep banks and intertidal shorelines are usually the areas at greatest risk. In this regard, the shorelines of the St. Lawrence River would be at risk since high rates of crab burrowing in combination with water level fluctuations and wave action might contribute to accelerated bank erosion and collapse, particularly on the river islands downstream from Montréal. Deposition of eroded sediments can also change the composition of the substrate and therefore alter river and lake habitats. The bank erosion caused by burrowing crabs could eventually increase water turbidity and affect general river water quality.

Crabs living in polluted waters could bioaccumulate various compounds to harmful levels which may be transferred to predators that consume the crab (Hymanson et al., 1999). Arsenic, selenium and DDT derivative (DDE) were detected in the body tissues of 36 crabs from California, but levels were generally low and below threshold values for human consumption (CMCWG, 2003). Many volatile compounds which may determine the flavour quality of the crab meat were also found in Chinese mitten crabs (Chen and Zhang 2006). No data exist on the nature and levels of chemical contaminants in Canadian *E. sinensis* crabs.

6. SUMMARY

The compilation of information concerning the ecology, distribution, life history and potential impacts of the Chinese mitten crab will be used to assess its capacity to invade quite different aquatic systems in the northern hemisphere, and to spread and successfully establish itself there. Over the past 15 years, the species has been first reported in a large array of countries, suggesting a range extension due to accidental introduction. The import of live crabs for food and the discharge of ship ballast water are considered to be the two main pathways of the introduction and transfer of the species across countries. Ship ballast water discharge most probably explains the repeated cases of introduction of the species in the Great Lakes–St. Lawrence River basin over the past 40 years. Over the past three years, the species has been reported from Thunder Bay on Lake Superior down to the St. Lawrence estuary, as well as in some large estuaries (Chesapeake Bay, Delaware Bay) on the east coast of United States and at a number of other locations in the world. This suggests that quite effective pathways of introduction and transfer most probably associated with international

shipping are still acting over large areas, despite the implementation of guidelines for ship ballast water exchange in Canada and the United States since 1990.

At the moment, there is no evidence of any established population of *E. sinensis* in Canadian waters, but the presence of the crab in the St. Lawrence River and estuary may increase the risk of establishment and invasion. If *E. sinensis* ever becomes established in Chesapeake Bay or other estuaries along the east coast of the United States, it could spread northwards and eventually reach the Atlantic provinces of Canada. Rivers and estuaries along the Pacific coast are also identified as suitable environments for the survival of Chinese mitten crab populations (Herborg et al., 2007a).

Once established, the Chinese mitten crab would surely represent a new environmental pressure on Canadian aquatic systems. It would be the first freshwater crab in Canada and could have detrimental impacts on the diversity and the food web of our waters.

Acknowledgements:

The authors wish to express their gratitude to Leif-Matthias Herborg (DFO) for the information sources and the geographical data for Chinese mitten crab distribution. Our sincere thanks go also to François Boudreault (Environment Canada) for map drawings and to Jean-Marc Gagnon (CMN, Ontario), Mike Friday and Vicky Lee (MNR, Ontario) for their help concerning the validation of information on the capture of mitten crabs in the Great Lakes-St. Lawrence Seaway. Helpful suggestions and information were also provided by Becky Cudmore, Chris McKindsey and Nicholas Mandrak. Special thanks go to Fisheries and Oceans Canada's Centre of Expertise for Aquatic Risk Assessment for providing funding.

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Table 1: Information summary of the captures of *Eriocheir sinensis* in the Great Lakes-St. Lawrence River basin (date, location and size).

Year	Date	Body of water	Location	Sex	Size of carapace		Weight (g)	Comments
					Length (mm)	Width (mm)		
1965	October 4	Detroit River	Near Belle Isle, Windsor, ON	M	59.3	68.2		Data from Jean-Marc Gagnon, National Museum of Natural Sciences, Ottawa
1973	April 12	Lake Erie	32,2 km SE of Eriean, ON	F	57.3	65.0	124.5	Data from Vicki Lee, Lake Erie Management Unit, Wheatley, ON
1973	April 26	Lake Erie	9,7 km WSW of Eriean, ON	M	64.3	74.4	201.1	Data from Vicki Lee, Lake Erie Management Unit, Wheatley, ON
1973	May 24	Lake Erie	12 km SxW ½ of Port Stanley, ON	M	60.0	68.7	145.8	Data from Vicki Lee, Lake Erie Management Unit, Wheatley, ON
1975	May 17	Lake Erie	Municipal dock Lorain, OH	M	71.0	80.0		Data from the Ohio Division of Wildlife, Lake Erie Fisheries Station (now Sandusky Fisheries Research Unit), Sandusky, OH
1978	May 10	Lake Erie	3.2 km SE of Pelee Island, ON	M	59.6	65.3	163.0	
1981	May 25	Lake Ontario	Half Moon Point, ON	M	76.0	82.0	296.0	
1984	April 23	Lake Erie	18 km SE of Wheatley, ON	F	66.4	73.5	198.0	Data from Maureen Zubowski, Royal Ontario Museum, Toronto, ON
1991	November	Lake Erie	4 km W of East Sister Island					Identity not confirmed (caught and reported by commercial fisherman G. Penner of Kingsville, OH)
1994	April 9	Lake Erie	7 km ESE of Wheatley, ON	M	61.0	68.2	183.0	
1994	April 25	Lake Erie	30 km ESE of Eriean, ON	F	57.0	67.0	90.0	

1996	April 17	Lake Erie	Cedar Point Sandusky, OH	M	73.0	79.0	274.0	Data from the Ohio Division of Wildlife, Lake Erie Fisheries Station (now Sandusky Fisheries Research Unit), Sandusky, OH
2004	March 18	Lake Erie	Near Wheatley, ON	M	65.0	70.0		Data from Maureen Zubowski, Royal Ontario Museum, Toronto, ON
2004	September 2	St. Lawrence River	Near Lévis (St-Romuald), QC	F		46.0	39.6	Data from Yves de Lafontaine, Environment Canada, Montreal
2004	Fall	St. Lawrence River	Ste-Agèle-de-Laval, QC					Identity not confirmed (caught and reported by a commercial fisherman)
2005	March 7	Lake Erie		F	70.0	74.0		
2005	September 2	St. Lawrence River	Mouth of St-François River, QC	M		37.8	25.5	Data from Yves de Lafontaine, Environment Canada, Montreal
2005	December 8	Lake Superior	Mission Island Thunder Bay, ON	M	60.0	65.0	110.0	Data from Mike Friday, Ontario Ministry of Natural Resources, Thunder Bay, ON
2006	July 11	St. Lawrence Estuary	La Pocatière, QC	M				Identity not confirmed (caught and reported by a commercial fisherman)
2006	July 11	St. Lawrence Estuary	La Pocatière, QC	M				Identity not confirmed (caught and reported by a commercial fisherman)
2006	September 30	St. Lawrence Estuary	La Pocatière, QC	F		65.0		Contact Guy Verreault (Fapaq, Gouv, Qc)
2006	October 9	St. Lawrence River	South shore Lake St-Pierre, QC	M		72.3		Data from Yves de Lafontaine, Environment Canada, Montreal
2006	October 21	Lake Superior	Mission Island Thunder Bay, ON	F	55.0	62.0	83.0	Data from Mike Friday, Ontario Ministry of Natural Resources, Thunder Bay, ON
2007	May 11	Lake Erie	Municipal pier, Lorain, OH	M				The Morning Journal, Ron Vidika reporter, May 12, 2007

Table 2: Distribution of the 7 haplotypes in crabs from China, Europe and North America (West and East Coasts)

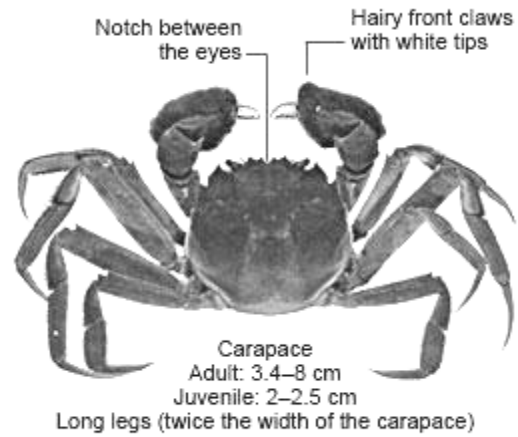
(adapted from Hänfling et al. 2002; Tepolt et al. 2007)

Country	Location	Haplotypes							n
		ES1	ES2	ES3	ES4	ES5	ES6	ES7	
China	Liaohoe	1	3	2					6
	Yangtze	4	3			1		2	10
	Hangzou	3	2			1			6
Europe	Elbe	7			3	5			15
	Lake Laascher See	7			5	3			15
	Weser	8		1	3	2			14
	Thames	7			4	4	1		16
	Tagus	13			2	1			16
West United States	Sacramento				7				7
	San Francisco				16				16
East Canada	St. Lawrence River (freshwater)	2				1			3
	St. Lawrence Estuary					1			1
	Lake Erie	1			2	1			4
	Lake Superior				1				1

Table 3: Maximum upstream location and distance from the river mouth of Chinese mitten crabs records in different rivers within its established range

River	Country	Maximal upstream distance traveled (km)	References
Yangtze	China	1400	Cohen and Weinstein, 2001
Elbe	Czech Republic	700	Panning, 1938
Oder	Poland	464	Herborg et al., 2003
Rhine	Germany	512	Herborg et al., 2003
Tagus	Portugal	80	Costa and Cabral, 1999
Thames	United Kingdom	150	Clark et al., 1998
Midi canal	France	504	Petit, 1960
San Joaquin	United States (CA)	400	Rudnick et al., 1999, 2000
Sacramento	United States (CA)	250	Cohen and Weinstein, 2001

a)



Michael Creighton and Dr Robert Bailey, University of Western Ontario

b)



Figure 1. Chinese mitten crab (*Eriocheir sinensis*). (a) Major identification features; and (b) differentiation between female (upper) and male (lower)

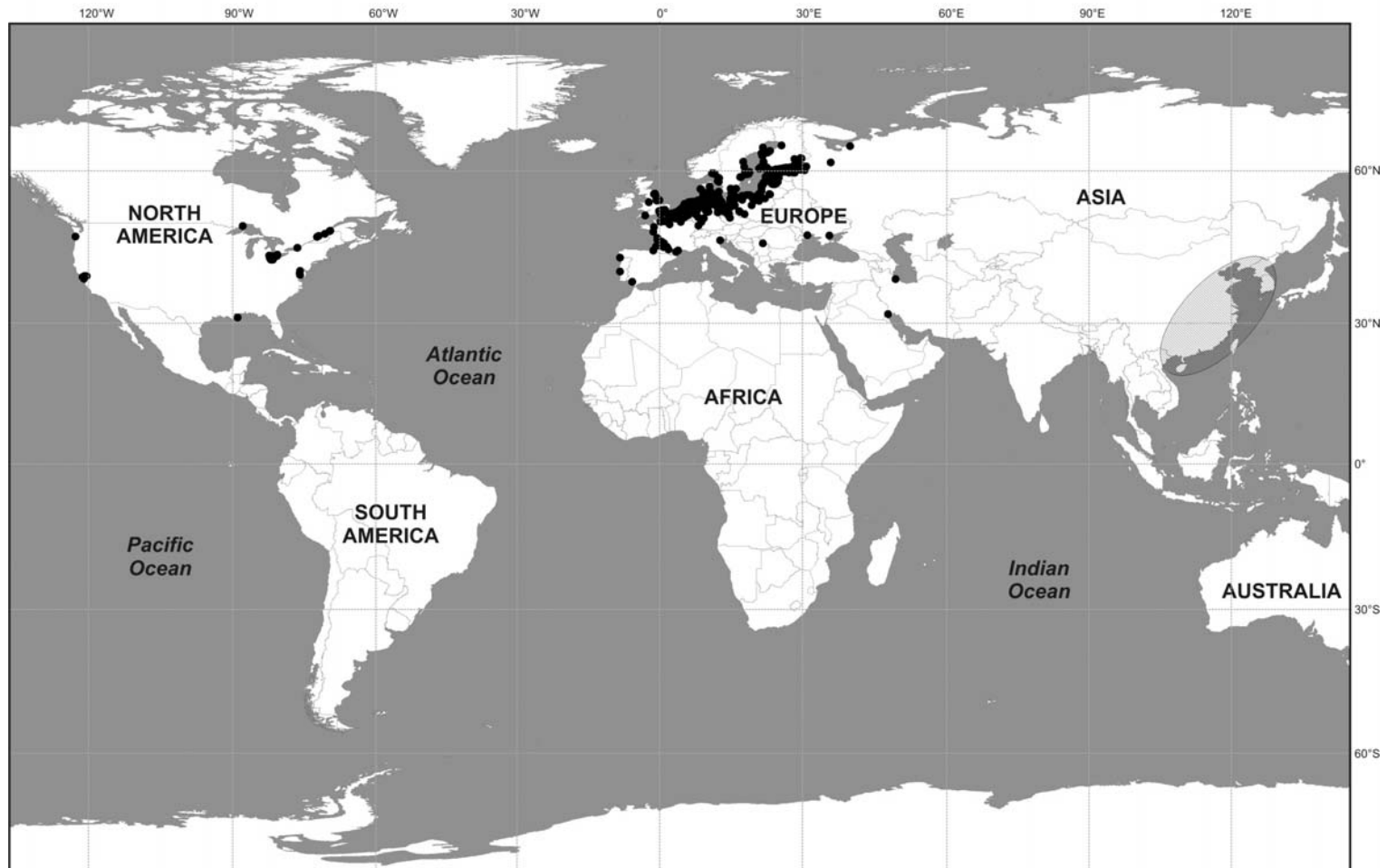


Figure 2. Worldwide distribution of Chinese mitten crab sightings (*Eriocheir sinensis*) (shaded area: native range; dots: introduced occurrences)

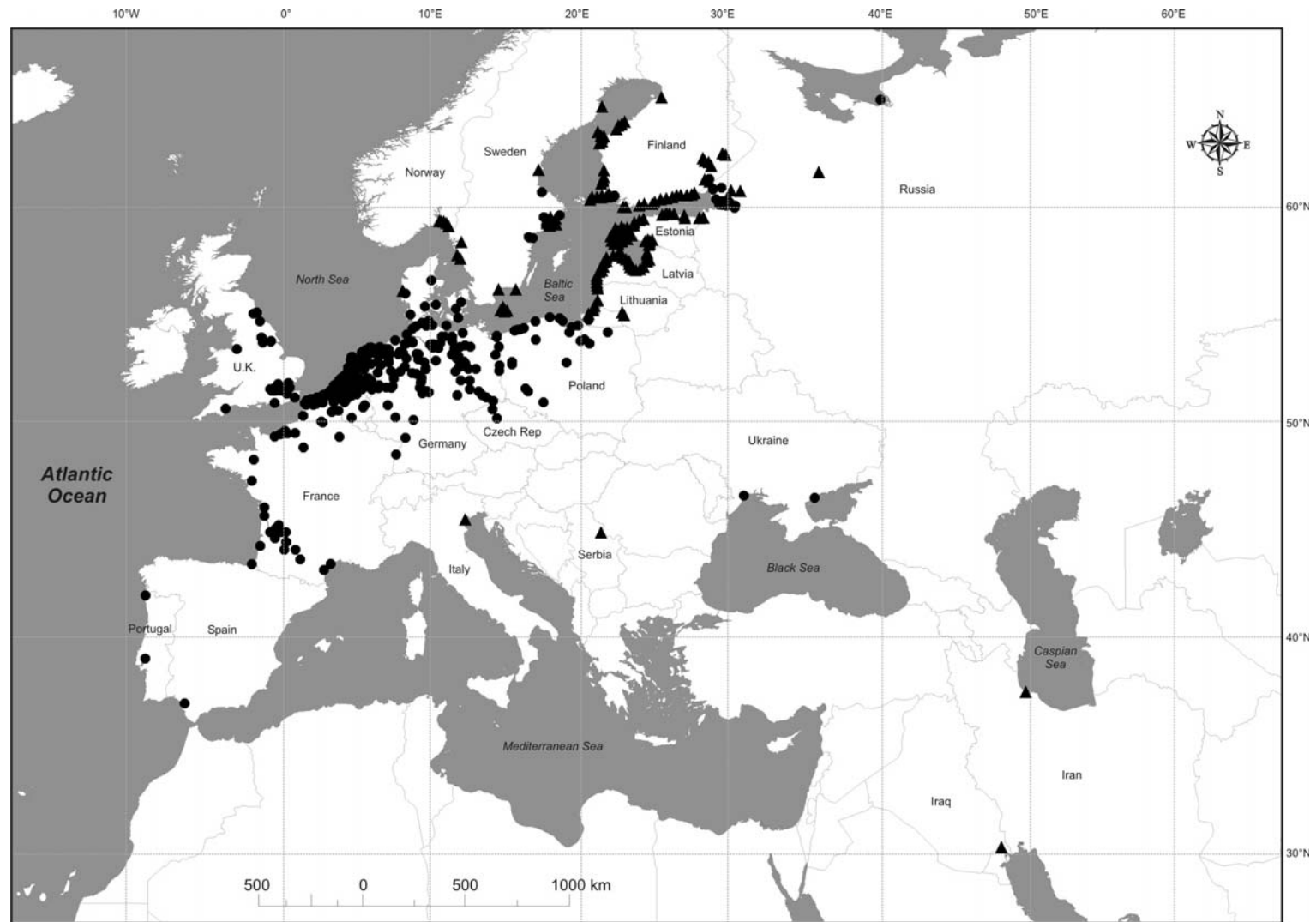


Figure 3. European distribution of the Chinese mitten crab (*Eriocheir sinensis*) (note: ● are for established locations and ▲ are for sightings where the establishment is not confirmed or never occurred to date)



Figure 4. Chinese mitten crab (*Eriocheir sinensis*) occurrences in the United States (adapted from USGS) (note: ● are for established locations; ▲ are for sightings where the establishment is not confirmed or never occurred to date; the specimen found in the Columbia River (★) was identified as *Eriocheir japonica*)

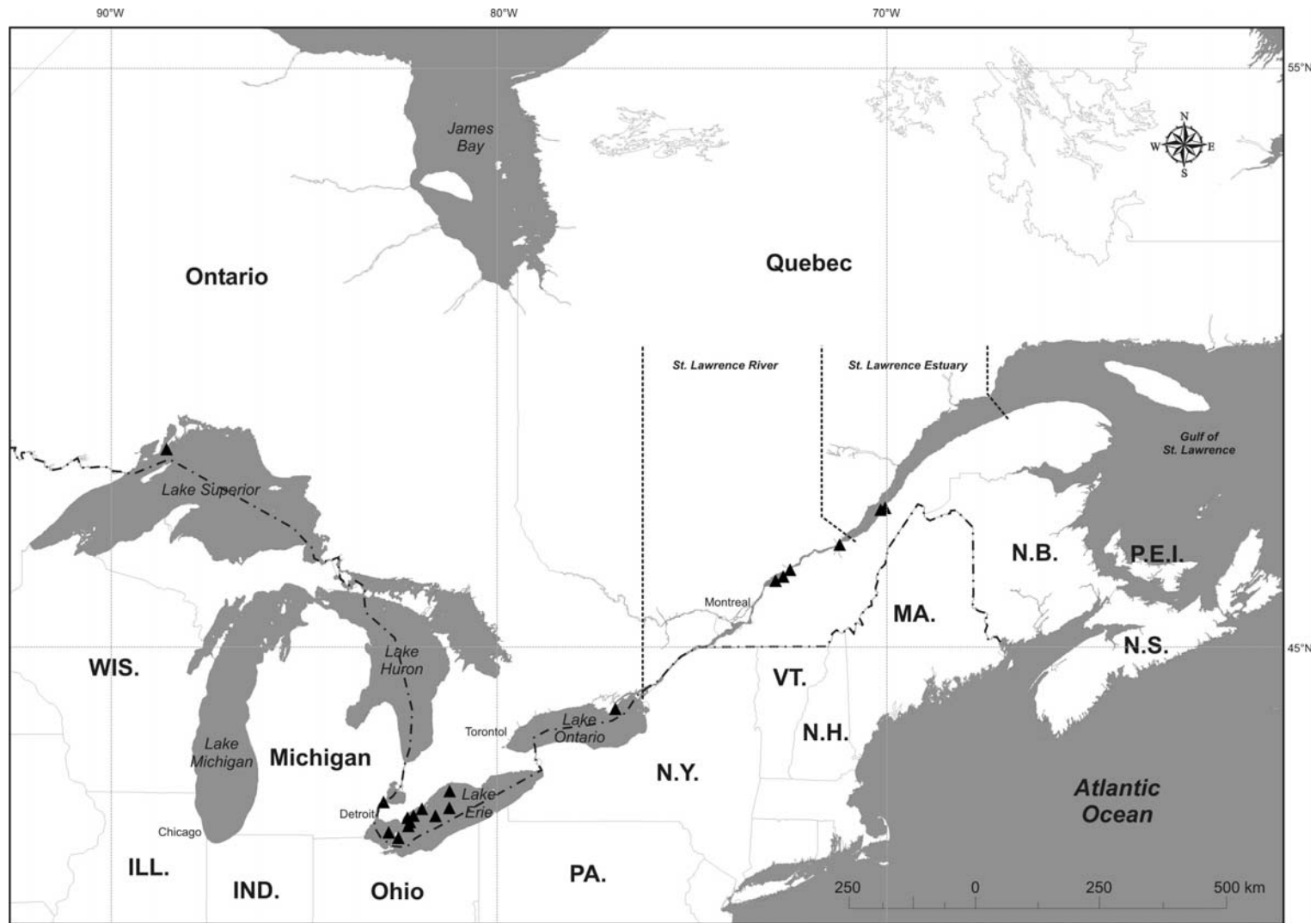


Figure 5. Canadian records of the Chinese mitten crab (*Eriocheir sinensis*)

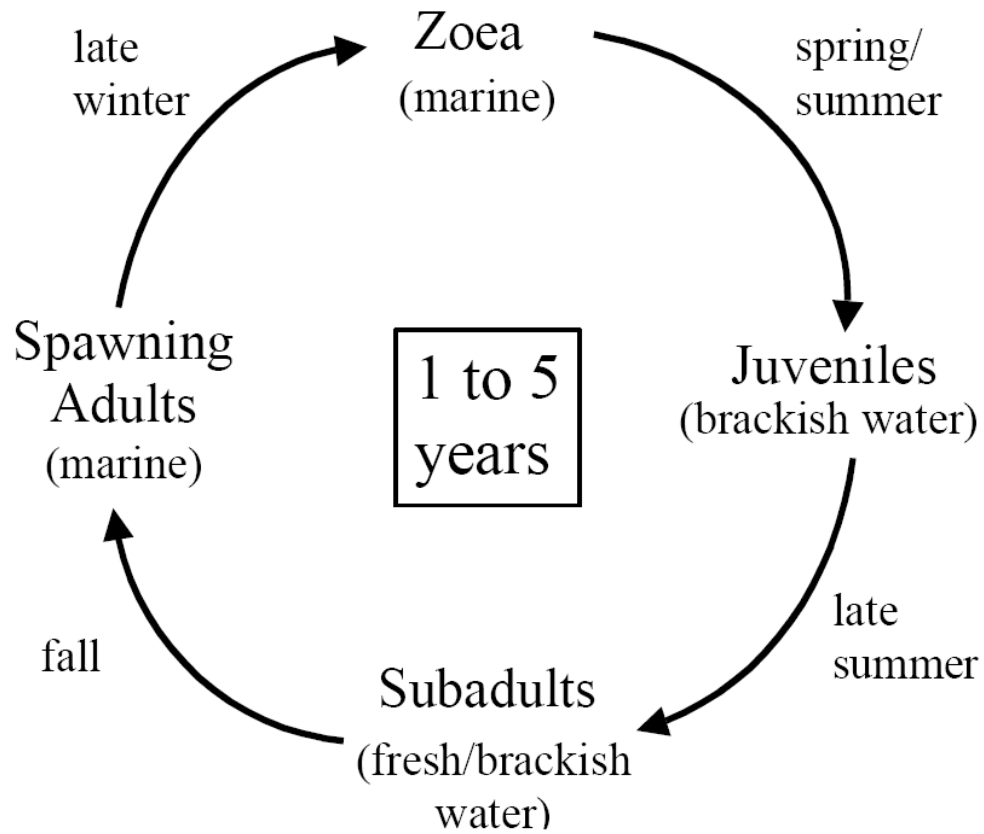


Figure 6. Summarized life cycle of the Chinese mitten crab (from Rudnick et al., 2000)

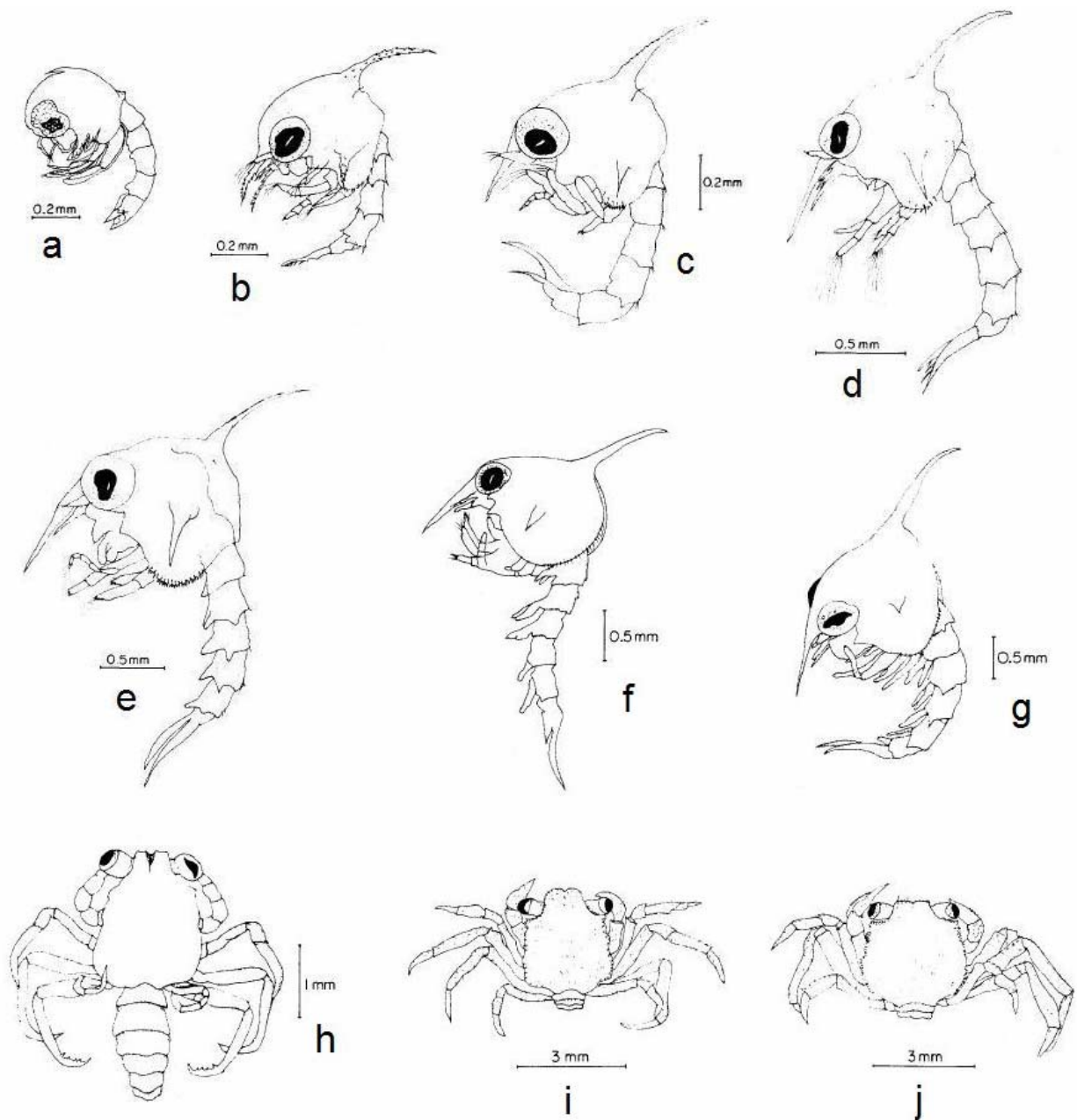


Figure 7. Developmental stages of the Chinese mitten crab (lateral view of zoeal stages, dorsal view of Megalopa and early juvenile stages). (a) prezoa, (b) Zoea I, (c) Zoea II, (d) Zoea III, (e) Zoea IV, (f) Zoea V, (g) Zoea VI (additional stage), (h) Megalopa, (i) crab I and (j) crab II (adapted from Montú et al., 1996)

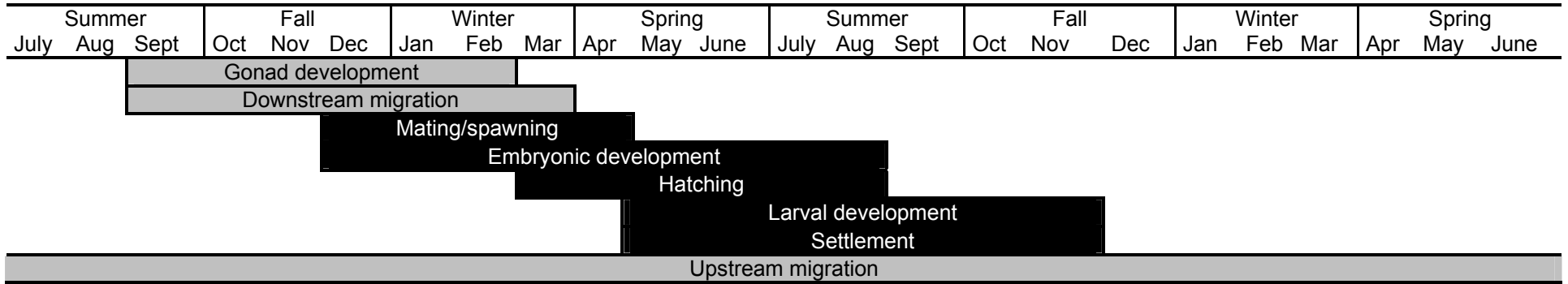


Figure 8. Summary of the season and location (grey: river/estuary; black: estuary) of occurrence for the various life stages of the Chinese mitten crab (adapted from Cohen and Weinstein, 2001)

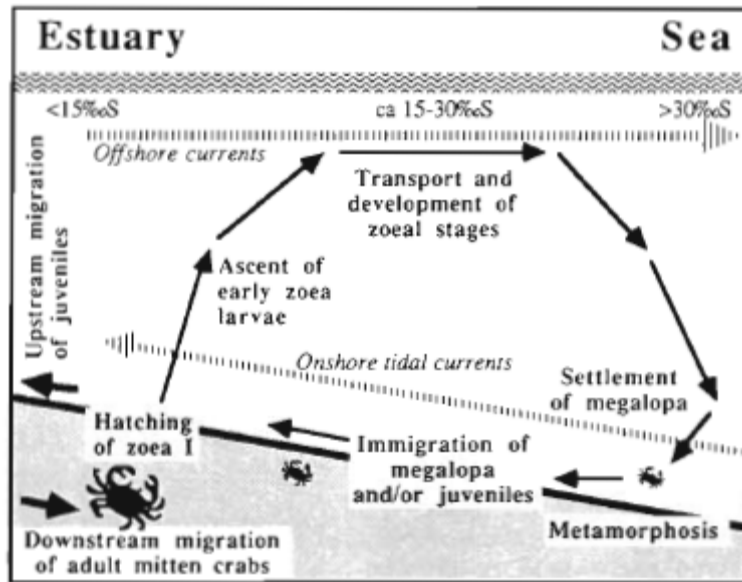


Figure 9. Schematic view of the use of currents by the larval stages of the Chinese mitten crab during its development (from Anger, 1991)