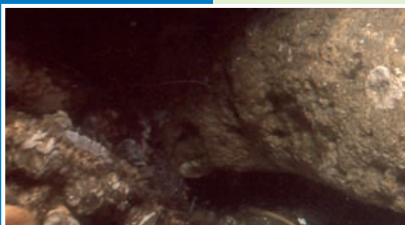
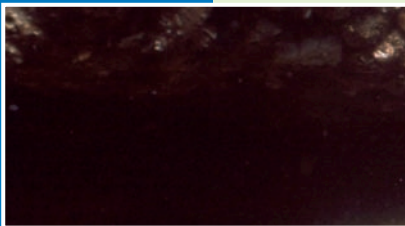
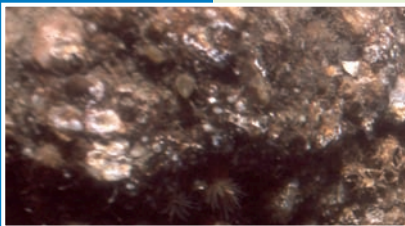


# A risk analysis of the Chinese mitten crab in The Netherlands



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## Preface

The Chinese mitten crab is an exotic crustacean already present in high numbers for many years. To get more of an insight into the occurrence of the Chinese mitten crab in The Netherlands, any possible ecological, economical and social impacts, and the possibilities of risk management the Team Invasive Alien Species of the Ministry of Agriculture, Nature and Food Quality have commissioned Bureau Waardenburg to carry out a risk analysis.

The following employees of Bureau Waardenburg carried out this risk analysis:

ir. D.M. Soes (project leader and report)

drs. S. Bouma (report)

Msc M. Collier (review)

The project was supervised by Mrs. dr. ir. José H. Vos and ir. J.W. Lammers from the Team of Invasive Alien Species of the Ministry of Agriculture, Nature and Food Quality.

We want to thank the following experts for their efforts and contribution to the literature review on the ecology and effects of the Chinese Mitten Crab carried out by Bureau Waardenburg in 2006 (Soes *et al.*, 2007), which formed the basis for this risk management: A. Kikkert (Rijkswaterstaat), M. Ohm (Rijkswaterstaat), G. Van de Velde (KUN), H. Wannings (Waterschap Hunze en Aa's), T. Bult (IMARES), J. Wanink (Koeman en Bijkerk), G. Timmermans, M. Melchers (Gemeente Amsterdam), T. Claassen (Wetterskip Fryslan), R. Noordhuis (Rijkswaterstaat), F. Kerkum (Rijkswaterstaat), S. Langeweg (Waterschap Hollands Noorderkwartier), P. Heuts (Hoogheemraadschap Stichtse Rijnlanden), J. Samuels (Waterschap Brabantse Delta), B. Spekke (Waternet), P. van Beers (Waterschap Veluwe), M. Beers (Waternet), H. Adema (Naturalis), T. Eggers (Germany), D. Holdich (England), L. Roelen and R. Lipmann.

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## Summary

The Chinese mitten crab (*Eriocheir sinensis*) originates from the coastal rivers and estuaries in North China and Korea, extending from the West coast of Korea by the Yellow Sea to the Fukien province south of Shanghai (Panning, 1938; Cohen & Carlton, 1995). Since the late 1920s - early 1930s this species has drastically extended its range by invading many countries in Europe and North America.

Crabs can easily be introduced via rivers from the neighboring countries Germany and Belgium (e.g. transport of larvae by currents, dispersal of adults and juveniles) where they also occur in high densities. Crabs can also be introduced in The Netherlands via ballast water in ships from their native range or countries where they have been able to establish exotic populations. Other introduction pathways in The Netherlands include (intended and unintended) transport by humans for example introduction for research - or commercial (trade for consumption) purposes and escape or release from public aquaria.

Chinese mitten crabs were first confirmed in The Netherlands in 1931 although commercial fishermen in the Ems-Dollard estuary were already catching them in the period between 1929-1930. Since then this species has been able to invade all Dutch provinces in a very short period of time and in some areas the numbers increased to such levels that they have been regarded as a plague. It has established and is now widespread throughout The Netherlands. The highest densities are found in coastal provinces and larger inland rivers and streams

### Impact

Chinese mitten crabs have been nominated as among 100 of the "World's Worst" invaders as it has the potential to cause serious ecological, economic and social impacts. Further more they might interfere with the goals of various European Directives such as the Water Framework Directive (WFD) and Habitat Directive. Although many impacts have been described in the literature, hardly any of them have actually been observed or quantified in the field. With present knowledge only negative impact on inland fisheries can be classified as high.

Burrowing activities of Chinese mitten crabs can induce the release of phosphates and pollutants that are stored in the sediment. Depending on the substances present in the sediment and their concentrations this may consequently affect the water quality. Burrowing activities can also reduce the water clarity negatively impacting the development and growth of aquatic plants.

Because of their omnivorous and opportunistic feeding habits Chinese mitten crabs can have an impact on resident flora and fauna species in The Netherlands, some of which might be species from Red List or Natura 2000. Especially impact on fish reproduction due to predation of fish eggs seems to be of great concern, but actually confirmed records are lacking.

The Chinese mitten crab can function as a secondary host for the Asian lung fluke (*Paragonimus westermani*), but the probability of establishment of this parasite in Dutch waters is small, because of the low tolerance to low water temperatures of its primary hosts.

Burrowing activities of the Chinese mitten crab can cause erosion of riverbanks. The consequences of a breakdown of a bank depend on the function of the particular bank (e.g. protection against flooding, directing the water flow) and the land use adjacent to the water system (e.g. agriculture, nature reserve), but could include alteration of the course of a waterway or damage to agricultural crops. After 80 years of presence no damage has been reported in the Netherlands yet and it is therefore expected to be of low concern.

Chinese mitten crab can have high, negative impact on commercial fishermen by damaging fishing gear, consuming (part of) the fish caught in the traps, extending the handling time to sort the fish from the crabs and by stealing bait. The crabs can be sold for consumption generating income for commercial fishermen, but the very variable amount of crabs offered for auction keeps the price relatively low and accumulation of toxic substances in crabs (bioaccumulation) could pose a health risk for humans.

Chinese mitten crabs can block cooling water and other water intake systems of industrial companies. Damage and cost generated solely by the Chinese mitten crab are expected to be of low economic importance.

Chinese mitten crabs interfere with recreational fishermen through bait stealing. To avoid interference fishermen have to abandon their traditional fishing grounds. During their migration crabs are reported in urban areas like backyards, playgrounds and even inside houses or apartments. These social impacts are of low concern.

### **Management**

Support measures to ensure the success of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (2004) will come too late for The Netherlands with an already established Chinese mitten crab population, but are of great importance for the prevention of spread to countries with no Chinese mitten crab populations.

Preventing further spread of the Chinese mitten crab in The Netherlands will be difficult because of the many different pathways that can be used by crabs to invade new areas, together with the already high abundance in especially the coastal provinces and larger inland rivers and streams, the high reproductive rate of this species, its wide range of physiological tolerances and its ability to migrate over land. In preventing further spread a change in legislation forbidding the stocking of Chinese mitten crabs can be considered to prevent the colonization of Chinese mitten crab areas.

In countries where Chinese mitten crabs have established populations researchers have experimented with a variety of physical controls to reduce Chinese mitten crab populations, but no cases of fully successful eradication have been reported. Complete eradication in The Netherlands is also unlikely. Physical control methods to reduce the number of crabs in The Netherlands could include (selective) fishing and trapping during migration events at locations where a river or stream is contained by a regulatory structure (e.g. dam, fish migration facility). Another possibility is the installation of travelling screens and trash racks at locations at the same locations as described above.



# 1 Introduction

The Chinese mitten crab (*Eriocheir sinensis*) originates from the coastal rivers and estuaries in North China and Korea, extending from the West coast of Korea by the Yellow Sea to the Fukien province south of Shanghai (Panning, 1938; Cohen & Carlton, 1995). Since the late 1920s - early 1930s this species has drastically extended its range by invading many countries in Europe and North America.

Further spread of this species worldwide is very likely. This is because of the many different introduction pathways that can be used by this species to invade new areas, together with its wide range of physiological tolerances, omnivorous and opportunistic feeding strategy, high reproductive rate and ability to migrate over land. Chinese mitten crabs have been nominated as among 100 of the "World's Worst" invaders (Kelly & Maguire, 2009).

Chinese mitten crabs were first confirmed in The Netherlands in 1931 although commercial fishermen in the Ems-Dollard estuary were already catching them in the period between 1929-1930. Since then this species has been able to invade all Dutch provinces in a very short period of time and in some areas the numbers increased to such levels that they have been regarded as a plague. In the present situation the highest densities are found in coastal provinces and larger inland rivers and streams (Soes *et al.*, 2007).

The Chinese mitten crab has the potential to cause serious ecological, economic and social impacts and can therefore interfere with the goals of various European Directives such as the Water Framework Directive (WFD) and Natura 2000.

In this study, commissioned by the Ministry of Agriculture, Nature and Food Quality Team Invasive Alien Species, a risk analysis was undertaken to provide more insight into the present distribution of Chinese mitten crabs in The Netherlands, its (potential) impacts, the probability of entry (introduction pathways), the probability of establishment, the probability of further spread and endangered areas. Subsequently, measures are identified to prevent further spread of this species and eradication and physical control methods are described that can be used to reduce the number of Chinese mitten crabs in The Netherlands.



## 2 Biology and ecology of the Chinese mitten crab

### 2.1 Taxonomy

The taxonomy of the Chinese mitten crab (*Eriocheir sinensis*) is still under debate and the determination of its status has stimulated many recent genetic and morphological studies. At present the species belongs to the family Varunidae (Schubart *et al.*, 2000; Clark, 2006) and the genus *Eriocheir*. Currently five different species are distinguished within this genus: *E. sinensis*, *E. japonicus*, *E. hepuensis*, *E. leptognatha* and *E. recta*, but several recent studies have argued against maintaining these five species. For example molecular studies carried out by Zhao *et al.*, 2002 and Tang *et al.*, 2003 suggest that *E. hepuensis* should not be regarded as a separate species, but as a synonym of *E. japonicus*. Tang *et al.*, 2003 (who carried out research on nuclear DNA and mitochondrial DNA) did not find clear genetic differences between *E. sinensis* and *E. japonicus* either, but other studies, for example research on mitochondrial DNA carried out by Zhao *et al.* (2002) and research based on morphological characteristics by Guo *et al.* (1997), do show differences between *E. sinensis* and *E. japonicus*. Because of these antinomies the current preferred species name of the Chinese mitten crab is *Eriocheir sinensis*. If further research proves *E. sinensis* and *E. japonicus* to be one species the Chinese mitten crab needs to be called *E. japonicus*, as this last name is older.

### 2.2 Description and identification

The Chinese mitten crab is a decapod crustacean that is usually identified by the dense patches of setae, or hair, on the white-tipped claws of larger juveniles and adults. The claws are approximately of equal size with males having slightly longer claws than females of similar carapace width (Normant *et al.*, 2007). The carapace width of adults is generally 80 mm, but some larger individuals up to 100 mm wide can occasionally be found (Rudnick *et al.*, 2000; Veldhuizen, 2001). The carapace of adults is nearly square-shaped, being slightly wider than long. The colour of the carapace varies from brownish-yellow, mostly in juveniles, to greenish-brown in adults and recently moulted specimens (Hymanson *et al.*, 1999). 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 (Rudnick *et al.*, 2000). After reaching a size of approximately 10 mm in carapace width males and females can be distinguished by the shape of the abdomen. The abdomen of a female is rounded (U-shaped) and consists of seven segments; the abdomen of a male is narrower (V-shaped) and consists of five segments (see figure 2).

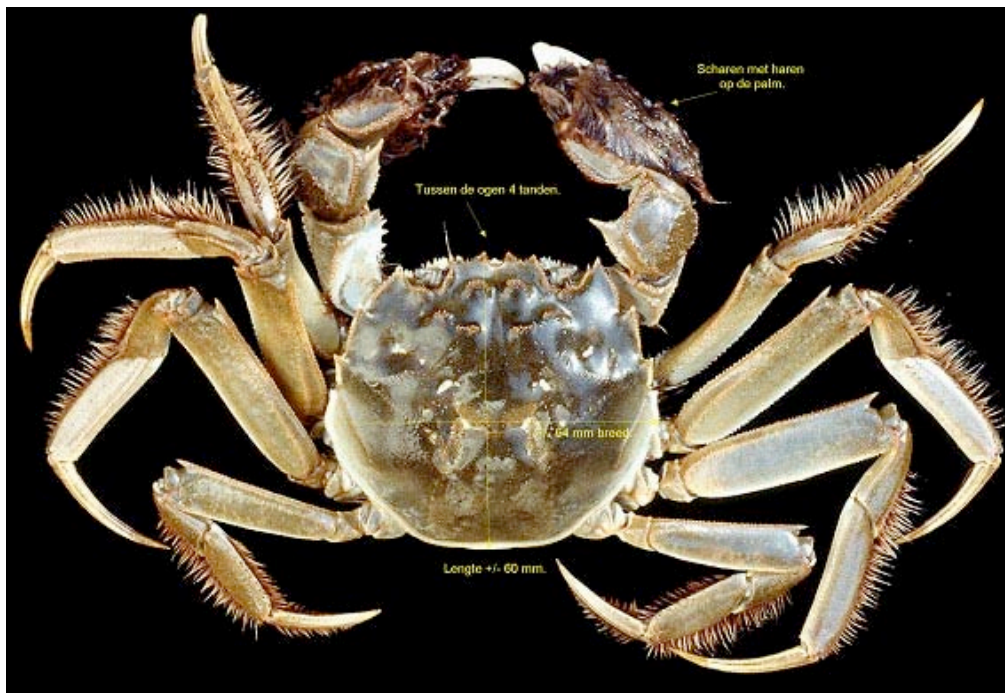


Figure 1 Identification characteristics of the Chinese mitten crab (Source: RIZA).

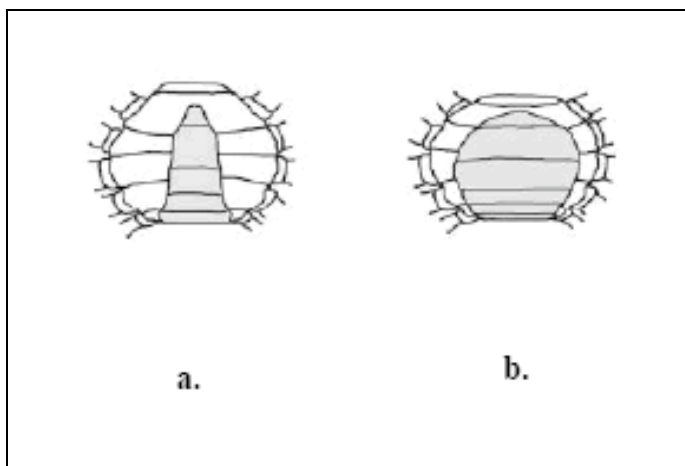


Figure 2 Abdomen of male (a.) and female (b.) Chinese mitten crabs (Source: Rudnick et al., 2000)

In freshwater systems in The Netherlands only two other species of crabs are present: the blue crab (*Callinectes sapidus*) and the Harris mud crab (*Rhithropanopeus harrisii*). Characteristics of these species are very distinctive from those of the Chinese mitten crab (figure 3) and therefore identification of the Chinese mitten crab in Dutch freshwater systems is relatively easy. Identification in marine systems, however, is more difficult due to the presence of more than 30 crab species in these waters ([www.krabben.nl](http://www.krabben.nl)). To identify of a Chinese mitten crab in these waters the characteristics described above should be used.





Figure 3 Blue crab and Harris mud crab. Pictures by J.H. Bergsma & A. Kikkert.

## 2.3 Distribution

### 2.3.1 Native range

The Chinese mitten crab is endemic to the Yellow Sea region bordering China and Korea, in Eastern Asia. Its native habitats are the coastal rivers and estuaries in North China and Korea, extending from the West coast of Korea by the Yellow Sea to the Fukien province south of Shanghai (Panning, 1938; Cohen & Carlton, 1995) with the Yangtze River in China being the largest river within its native range (figure 4).



Figure 4 Native breeding range of the Chinese mitten crab (source: Rudnick et al., 2000)

### 2.3.2 Established exotic populations

#### Invasion into Europe

The first report of the Chinese mitten crab in Europe was in 1912 in the Aller River, a tributary of the Weser River in Germany (Panning, 1938). Two years later (in 1914) the species was also discovered in the Elbe River, approximately 60 km east of the Weser River.

From Germany the species was able to reach the Baltic Sea, where it was first reported in 1926 (Panning, 1938; 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 generally less common along the northern shore (Ojaveer *et al.*, 2006). Over time, the crab migrated up the Elbe River as far as Prague in the Czech Republic and in the Oder River (Poland) up to Breslau (Herborg *et al.*, 2003).

Between 1920 and 1940 the Chinese mitten crab also extended its range westwards from Germany successfully invading The Netherlands, Belgium and Northern France. The crab spread into Belgium in the 1920s where it became a serious plague in the 1930s. In The Netherlands the crab is common since the early 1930s. It is believed the Chinese mitten crab entered France from Belgium during the 1930s where the first specimens were 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). By 1959 the crab had spread to the Mediterranean coast and was found in the Golfe de Garcone, near Spain (Welcomme, 1988). Since 1997 it also established itself in the Guadalquivir estuary, near Seville's harbour in Spain (Cuesta *et al.*, 2004). In the late 1980s the crab was found in the Tagus River in Portugal, where the species became established in 1990 (Cabral & Costa, 1999). These last two records represent the southernmost occurrences to date of the species in Europe.

The Chinese mitten crab was first reported in the Thames River (United Kingdom) in 1935, but only became established in 1973 (Ingle, 1986; Rainbow *et al.*, 2003). From that location the species spread to many other rivers in the United Kingdom (Herborg *et al.*, 2005). Records of mitten crabs in the Thames estuary remained relatively constant in the 1970s and 1980s (Clark *et al.*, 1998), but in the 1990s numbers escalated and there were huge increases in the numbers of crabs taken on the screens of West Thurrock, Tilbury and Lots Road (Chelsea) power stations (Clark *et al.*, 1998; Robbins *et al.*, 1999). The Chinese mitten crab was first found in the Waterford Estuary in Ireland in 2005 during routine fishing trawls and was subsequently recorded in the lower reaches of the River Suir and Barrow (Kelly & Maguire (2009). To date no established population has been found in Ireland, but an action plan to prevent the invasion and spread of this species in Ireland has been developed (Kelly & Maguire, 2009).

Two Chinese mitten crabs were collected in the Serbian section of the Danube River in June 1995 and November 2001, but evidence of established populations in that river has not yet been demonstrated (Paunovic *et al.*, 2004).

In May 2005 one individual crab was found in the central part of the Venice Lagoon in Italy (Mizzan, 2005).

Figure 5 shows the potential distribution of Chinese mitten crabs in Europe based on an environmental niche model developed with environmental data from its native range. Environmental parameters considered are: air temperature (max, mean, min), precipitation, wet-day frequency, elevation, river discharge, water temperature and watershed size. This model predicts that in Europe the Chinese mitten crab is likely to become even more distributed, including most watersheds of the Mediterranean Sea and the Black Sea basins (Herborg *et al.*, 2007).

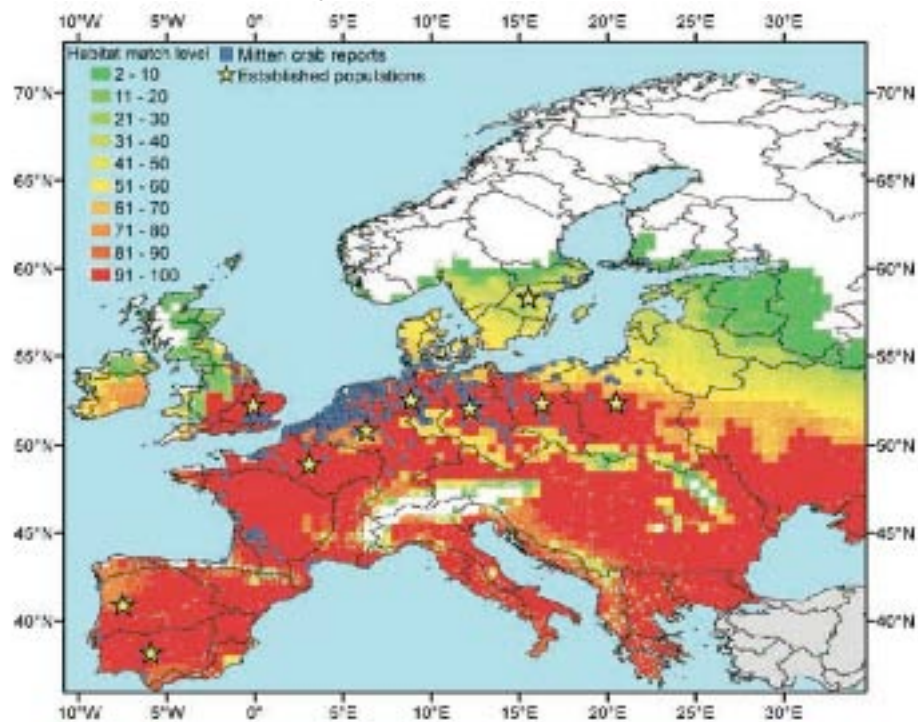


Figure 5 The potential distribution of the Chinese mitten crab in Europe. In different colours the habitat-match levels of an area as suitable for the Chinese mitten crab in its introduced range in Europe based on an environmental niche model developed with environmental data from its native range (Hagener *et al.*, 2007).

#### Populations in North America

The Chinese mitten crab was first recorded in Canada in 1965 when a specimen was caught in the Detroit River at Windsor, Ontario, in the Great Lakes. Since then several other records have been made from the same area, mostly from Lake Erie, (11 records between 1973 and 1996 and 7 records between 2004 and 2007), but the species never formed an established population (Veilleux & de Lafontaine, 2007) in the Great Lakes. More recently crabs have also been collected at various locations along the St. Lawrence River (one in September 2004, one in September 2005 and four in 2006).

In 1992 the Chinese mitten crab established itself in the San Francisco Bay (California) in North America. By 1998 the numbers in this Bay exploded and between 1998 and 2000 catches of adult crabs reached between 100,000 and 800,000 specimens per year in different parts of the bay (Rudnick *et al.*, 2003).

There are no further established populations of Chinese mitten crabs in North America, but several individual specimens have been recorded including two specimens in the mouth of the Patuxent River and on Chesapeake Bay in Maryland, one specimen outside the mouth of the Patapsco River in Baltimore's harbour in May 2005 and another specimen in the same river mouth in June 2006 (Ruiz *et al.*, 2006), four specimens in Delaware Bay in May 2007 and one in the Hudson River, New York in June 2007 (Veilleux & de Lafontaine, 2007).

#### Other exotic populations

Recent established populations of the Chinese mitten crab are known from the Volga River in Russia, the Sea of Azov between the Ukraine and Russia and the Black Sea area near Turkey (Shakirova *et al.*, 2007; Clark *et al.*, 2006).

In South-East Asia the Chinese mitten crab has been introduced in Vietnam for consumption (Hymanson *et al.*, 1999).

Recently Chinese mitten crabs have also been recorded in the Caspina Sea Region in Iran (Robbins *et al.*, 2006) and the Basrah Area of Southern Iraque (Clark *et al.*, 2006).

### **2.3.3 Colonisation of The Netherlands**

The presence of the Chinese mitten crab in The Netherlands was first confirmed in 1931, but commercial fishermen in the Ems-Dollard estuary were already catching them in the period between 1929-1930. The first records in 1931 were made from different areas including Groningen, Friesland, Zaandam, Brielse Maas, Reeuwijkse Plassen, 'Zuidhollandse Stromen' and the port of Rotterdam and four years after these records (in 1935) the species was found in almost all provinces of The Netherlands (figure 6).

The first introduction pathway is still under debate, but it is very likely that the species has been able to invade The Netherlands from the established population in the Weser River in Germany (Kamps, 1937).

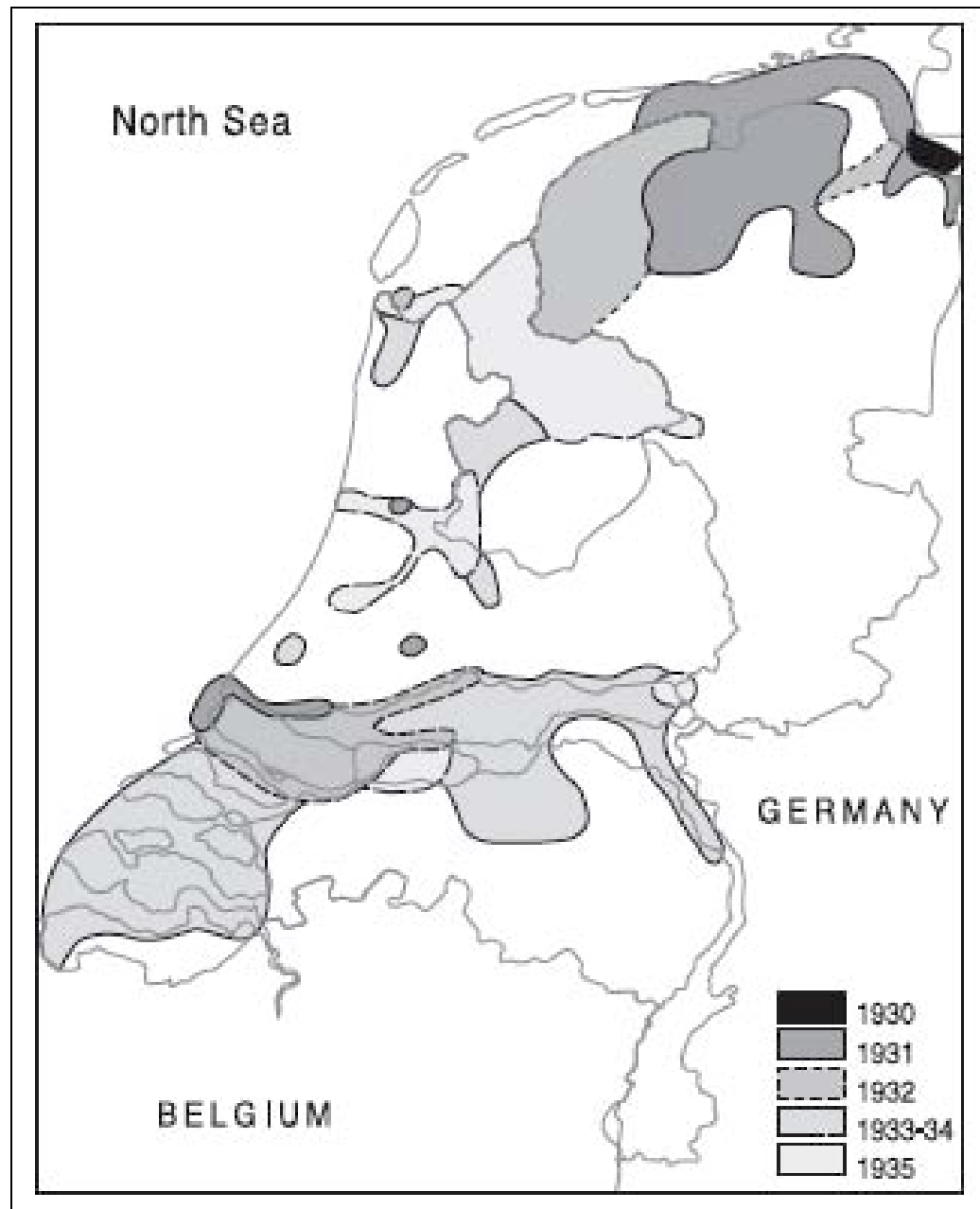


Figure 6 Colonisation of the Chinese mitten crab in The Netherlands between 1930 and 1935 (source: Kamps, 1937).

### 2.3.3 Current distribution in The Netherlands

At present the Chinese mitten crab is recorded in all provinces (figures 7 & 8), but the species is most abundant and widely spread in the coastal provinces of Groningen, Friesland, Noord-Holland, Zuid-Holland and Zeeland. Outside these coastal areas the Chinese mitten crab is most abundant in the larger river systems (Rivierengebied).

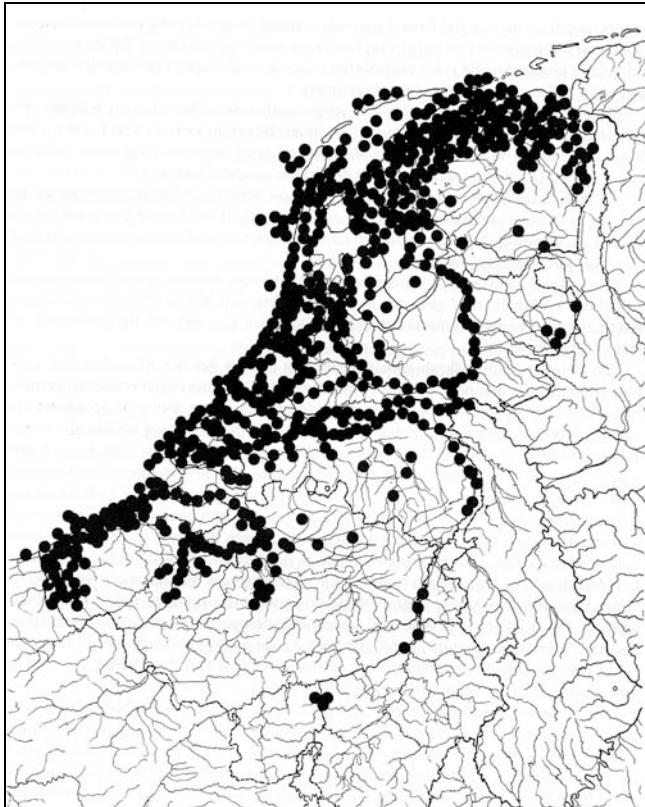


Figure 7 Distribution of the Chinese mitten crab in The Netherlands (source: Adema, 1991).



Figure 8 Distribution of 140 recent records (1978-2009) taken from [www.waarneming.nl](http://www.waarneming.nl). All records have been checked for reliability of the identification.

The Ministry of Transport, Public Works and Water Management (RWS) carries out both active (using nets) and passive (using fish traps) monitoring programmes to determine the status of fish stocks in large river water systems. Chinese mitten crabs caught in these programmes are also recorded. Data collected in the period between 1994 and 2006 have been analysed by Bureau Waardenburg and are presented in figure 9. This figure shows that the highest numbers of Chinese mitten crabs are recorded in downstream areas of the River Rhine system: Haringvliet, Nieuwe Waterweg, Hollands Diep, Amer and Noordzeekanaal and in Lake IJssel in the vicinity of the Afsluitdijk.

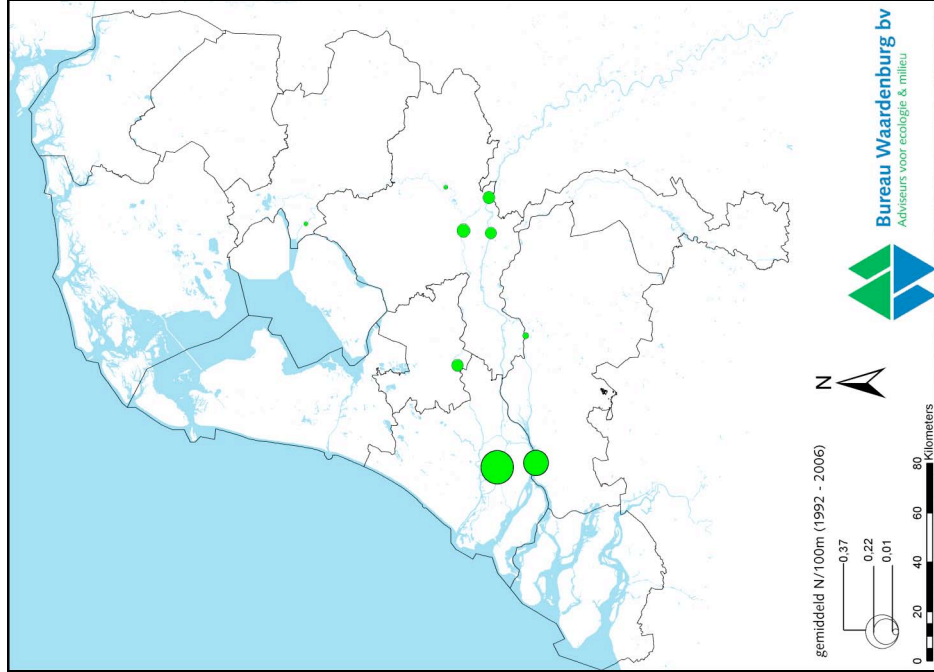
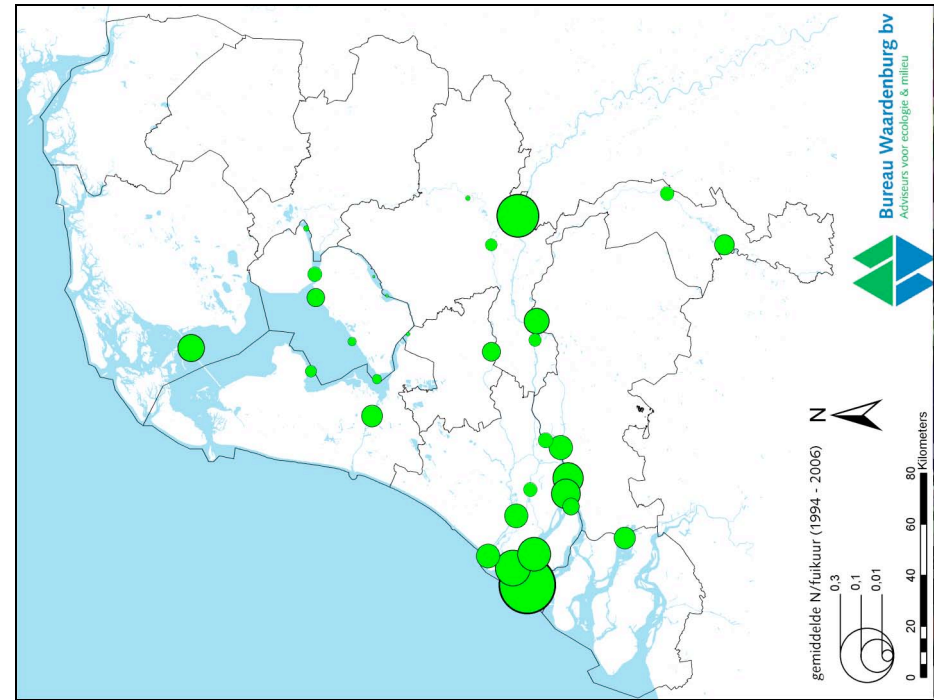


Figure 9 Average number of Chinese mitten crabs caught during passive monitoring (number of crabs per hour that a fish trap was placed; left figure) and active monitoring (average number of crabs caught per 100 meter; right figure) of fish stocks in The Netherlands between 1994-2006. Note: Data presented are only based on monitoring of RWS; Chinese mitten crabs are present in areas that are not covered by the RWS monitoring programmes. Source: Soes et al. (2007).



## 2.4 Life history

### 2.4.1 Life cycle

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. Dutch crabs in general mature after two years (Veilleux & de Lafontaine, 2007).

The Chinese mitten crab is an euryhaline species characterised by a catadromous life cycle. It spends most of its time in fresh or brackish waters, but needs brackish to salt water, generally found in estuaries, to reproduce. During the life cycle several phases can be distinguished including eggs, several larval stages, a juvenile phase and an adult phase. Timing of the different phases in the Netherlands is shown in figure 10.

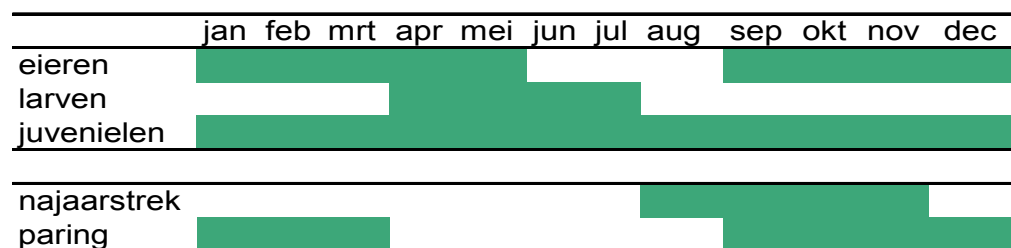


Figure 10 Timing of the various stages of the life cycle of the Chinese mitten crab in The Netherlands (source: Fladung, 2000).

After mating in estuaries in the period September/October-February/March females migrate to the open sea/ocean where the eggs are released. After the hatching of the eggs (which takes several months) the free-swimming larvae are planktonic for one to two months and pass through a series of development stages: a non-feeding pre-zoea stage, five zoea stages and one megalopea stage. The non-feeding pre-zoea stage is very brief and it takes only a few minutes to several hours before the first zoea stage is reached. The time needed to develop from one stage to another depends on the temperature and salinity of the water and takes between 4 and 15 days to develop from one zoea-stage to another zoea-stage and 20-30 days to develop from the last zoea-stage to the megalopea stage (Hanson & Sytsma, 2005).

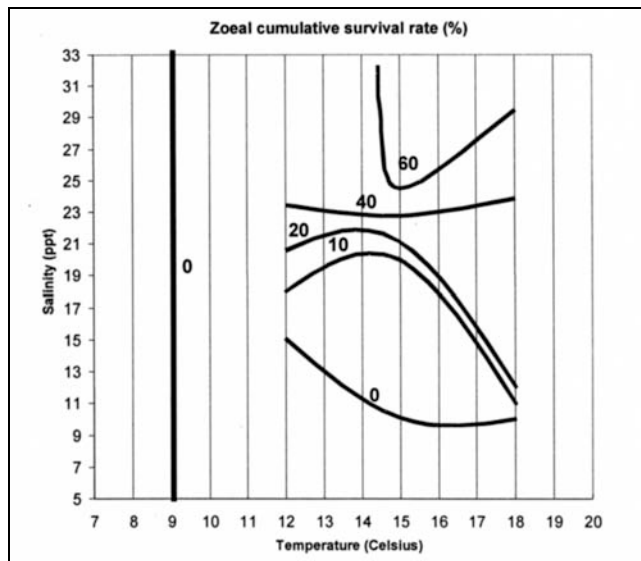


Figure 11 Cumulative survival rate for all different larval stages of the Chinese mitten crab (source: Hanson & Sytsma, 2005).

During this first zoea stage larvae have a high tolerance for low salinities, but this tolerance decreases during consequent stages including the megalopea stage. The optimum salinity to pass through all five zoea stages and megalopea stage is approximately between 20-25 ‰ (Hanson & Sytsma, 2005) and temperature between 18 and 25 °C. Larval development slows down when the temperatures are low and is impossible when temperatures drop below 12°C (Anger, 1991). Larvae are found in The Netherlands in the period between April and July (figure 10).

The growth of juvenile crabs (after the larval stages) is mainly influenced by the availability of food and the temperature of the water. The optimum temperature for growth is between 20 and 30 °C (Jin *et al.*, 2001). Juvenile crabs migrate from the estuaries to the freshwater systems generally in the period between April and June (Soes *et al.*, 2007). It takes two to five years for juveniles to reach the adult phase, so juveniles are found year round in The Netherlands.

#### 2.4.2 Reproduction

Chinese mitten crabs reach maturity when the carapace width is approximately 28-40 mm, but generally they start to reproduce when they reach a carapace width of 50 mm (Kamps, 1937; Adema, 1991). The reproduction process starts with migration to the estuaries where the brackish and salt water is found needed for a successful reproduction (§4.4.1). This migration takes place during the autumn between September/October-February/March (figure 10) with a speed of approximately 8-12 km per day (Panning, 1938). Factors stimulating this migration are not fully understood, but it could be a response to cyclic environmental conditions like decreasing day length or higher water flow and lower water temperature following heavy rain periods (Toste, 2001 cited in Rudnick *et al.*, 2005a).

After mating, the eggs (circa 250,000-1,000,000 depending on the size of the female) are attached under the abdominal flaps (see figure 2) of the females with a cement-like substance (Panning, 1938). This cement-like substance hardens with the salinity of the water, explaining why the crabs need saline waters for successful reproduction (Veilleux & de Lafontaine, 2007). Brooding the eggs, females migrate further into the open ocean where the eggs are released.

Both male and female crabs die after the mating process. Males die after mating, females after hatching and releasing the eggs (Zhao, in lit. cited in Soes *et al.*, 2007; Adema, 1991).

### **2.4.3 Habitat**

Juvenile and adult Chinese mitten crabs are found in a wide variety of habitats including both stagnant and dynamic water systems like small streams, rivers, canals and lakes (Adema, 1991; Kamps, 1937) even if they are highly modified and/or polluted (Hoestlandt, 1945; Ingle, 1986; Rudnick *et al.*, 2003). Therefore, the accessibility is probably the most important factor in whether a water system can be colonised by these crabs (Soes *et al.*, 2007).

Within a water system crabs show a preference for habitat types that can offer them food and protection against predators (see §2.4.5) like vegetation, stones and tree stumps. For this reason highest the densities of crabs are generally found close to the banks where these habitat types are generally found (Hanon & Sytsma, 2005; Heukels, 2006).

The temperature and salinity of the water are important factors for the development of the larvae (see §2.4.1), but adult crabs can survive at water temperatures ranging from 4 - 32°C and salinities ranging from 0 to 35 ‰ (Cohen & Weinstein, 2001).

Chinese mitten crabs can also survive for a relatively long time out of the water; up to 35 days in wet meadows (Nepszy & Leach, 1973) and 10 days in their burrows during a drought (Veldhuizen & Stanish 1999).

### **2.4.4 Diet**

The Chinese mitten crab is omnivorous and opportunistic in terms of its diet, feeding on almost everything it can get (Panning, 1938; Hymanson *et al.*, 1999; Rudnick *et al.*, 2000). Furthermore, its feeding habitat and diet shift during its life cycle (Hymanson *et al.*, 1999; Rudnick & Resh, 2005). Larvae feed on phytoplankton and zooplankton, while the diet of newly settled juveniles consists mostly of aquatic plants. When they grow bigger they also start feeding on live and/or dead animals.

Studying the stomach content of adult Chinese mitten crabs collected in Germany and California showed that most of their diet consists of plant material (like diatoms, filamentous algae, almost all higher plant species and fallen leaves from trees and

shrubs) and detritus (Thiel, 1938; Rogers, 2000). Aquatic plant species found in the stomach of the crabs included mainly *Potamogeton*, *Elodea* and *Lemna* (Veldhuizen & Stanish, 1999).

Animal material found in the stomachs of Chinese mitten crabs includes fish (mainly dead fish caught in fish traps), freshwater crayfish, insects and their larvae (especially *Chironomus*-larvae), Gammaridae, mussels, various snail species, Bryozoa, freshwater polyps (*Hydra*) and various worms (Peters & Panning, 1933; Thiel, 1938; Rogers, 2000). The crabs show a special preference for small mussel species like *Sphaerium*, *Musculium* and *Pisidium*, that are eaten completely, but they can also open up larger mussels like *Unio* and *Anadonta* and eat only their flesh (Peters & Panning, 1933). In The Netherlands they likely also feed on *Dreissena* species (Soes *et al.*, 2007).

In laboratory experiments Chinese mitten crabs also feed on live shrimps (Rogers, 2000), but it is uncertain if this also happens in the field.

#### 2.4.5 Predators

Humans are most likely to be the most important predator of Chinese mitten crabs. In China for example, they are a traditional food source and an important part of the aquaculture industry, yielding a high annual production (200,000 tons in 2000 (Chen & Zang, 2006)) worth approximately \$1,25 billion (Hymanson *et al.*, 1999). In The Netherlands they are consumed on a small scale by the Chinese minority, see also §3.5.

Apart from humans the Chinese mitten crab has many other natural predators. The following overview of known predators in Germany was given by Fladung (2000):

- mammals: brown rat, black rat, polecat and river otter;
- birds: grey heron, stork, ducks (including Red-breasted Merganser), crows and sea gulls;
- fish: eels, brown trout, common barb, perch, golden orfe, cod, pike, ruffe, elongate freshwater cod, pike-perch and big bream.

Juvenile and small adult crabs are likely mostly targeted by these predators. In The Netherlands it is likely that these smaller individuals are eaten by all bigger fish species feeding on benthic organisms such as eels, perch and roach (Soes *et al.*, 2007). Crabs with a carapace width of 7 cm or more can probably only be consumed by large pike and Welsh catfish, both not (yet) very abundant in The Netherlands (Soes *et al.*, 2007).

#### 2.4.6 Parasites and diseases

Several diseases have been described affecting the Chinese mitten crab including the parasitical barnacle *Polyascus gregaria*, epiphytical parasites, viruses and bacteria.

The parasitical barnacle is only reported within the native range of the Chinese mitten crab (see §2.3.1). This barnacle affects the reproduction organs of the crabs.

All epiphytical parasites known from the Chinese mitten crab belong to the genera *Zoothamnium*, *Vorticella* and *Epistylis*. These parasites attach themselves to the joints and gills of the crab causing for example breathing problems (www.fao.org).

Diseases of Chinese mitten crabs caused by viruses and bacteria (source: www.fao.org):

- shiver disease caused by a combination of a retrovirus and a bacteria causing shivering legs;
- vibriosis: disease caused by a bacteria leading to dying of the legs and abdomen;
- shell ulcer disease caused by bacteria solving chitine, a component of the carapace;
- black gill disease caused by a bacteria affecting the gills leading to breathing problems.

Other organisms like worms, nematoden, molluscs (snails and mussels), crustacea (*Harpacticoida* and *Amphipoda*), water mites (*Halacarida*) and *Chironomidae* have also been found on Chinese mitten crabs, but are not specifically related to this species and/or seem to affect these species (Normant *et al.*, 2007).



## 3 Risk analysis

In this chapter a risk analysis is provided for the Chinese mitten crab in The Netherlands using the information provided in chapter 2 'Biology and ecology of the Chinese mitten crab'.

### 3.1 The probability of entry

The worldwide spread of the Chinese mitten crab was due to human-mediated activities and not the result of natural causes (Cohen & Carlton, 1997). The following 10 pathways have been identified by Cohen & Carlton (1997) 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 vessel;
- transport of larvae or juveniles in ballast water;
- transport of adults or juveniles in fisheries products;
- transport of larvae in water with shipment of live fish;
- escape or release from research, public, or private aquaria;
- intentional transfer to develop a food resource.

Currently Chinese mitten crabs can enter The Netherlands from Germany, Belgium and other European countries (e.g. dispersal of larvae by sea currents, active dispersal of adults or juveniles, passive dispersal on floating material and ships), via ballast water in ships from countries where the Chinese mitten crabs has been able to establish populations (e.g. China, UK, Korea, Spain, Portugal and Denmark) or via transport by humans (e.g. introduction for research purposes or trade for consumption).

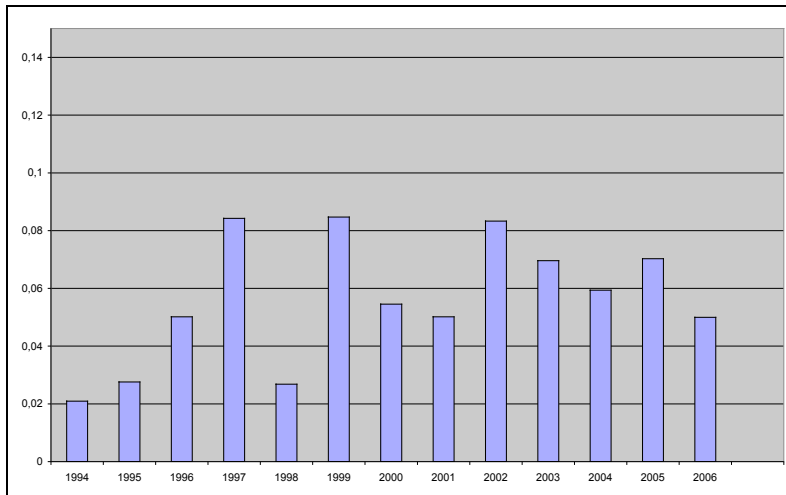
With the Chinese mitten crab being numerous in neighbouring countries and the Port of Rotterdam being one of the largest worldwide, with large numbers of infected areas coming in, the probability of entry is very high.

### 3.2 The probability of establishment

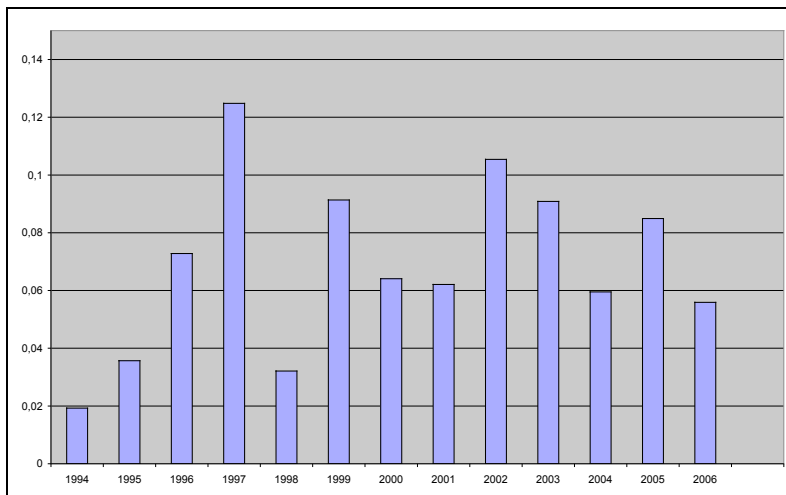
Since the first introduction in the Netherlands numbers of the Chinese mitten crab have increased to such levels that they were regarded as plagues in 1942, 1949, 1953, 1954, 1971, 1972, 1977, 1978, 1981-1985 (Adema, 1991). Since 1985 no more plagues have been reported, but the crab is still very common throughout The Netherlands. The average number of crabs caught during the months September-November (expressed in the number of crabs per hour that a fish trap was placed) in the period from 1994 to

2006 in the entire country of The Netherlands, in the so-called 'Rivierengebied', in the North Sea Canal and in the Lake IJssel district is shown in figures 12a to 12d. Looking at these numbers it can be concluded that the Chinese mitten crab has firmly established itself in The Netherlands, as numbers remain high throughout the different years.

As the Chinese mitten crab has proven to be able to establish large, stable populations the probability of establishment is very high.

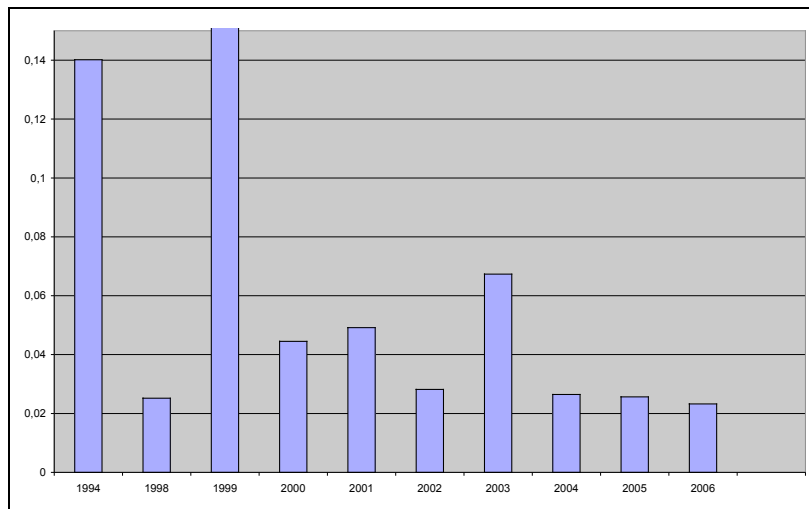


a) The Netherlands

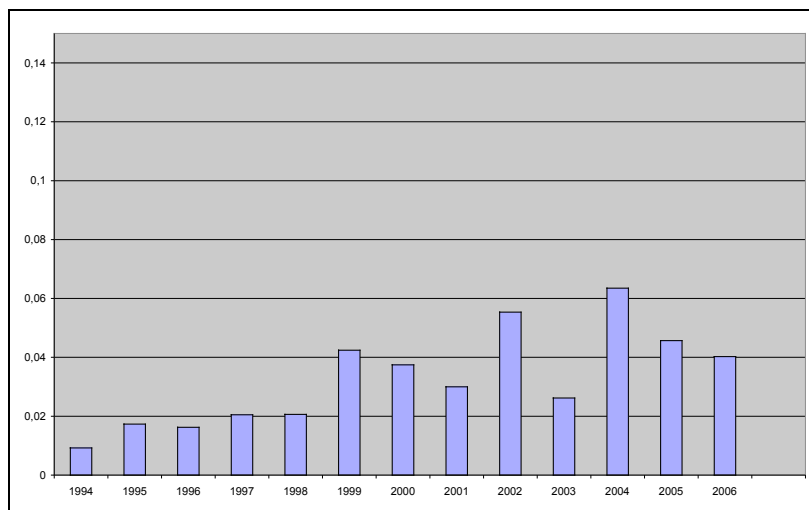


b) Rivierengebied





c) North Sea Canal (the average number in 1999 was 0.34).



d) Lake IJssel District

Figure 12 The average number of crabs caught during the months September-November (expressed in the number of crabs per hour that a fish trap was placed) in the period from 1994 to 2006.

### 3.3 The probability of spread

Within The Netherlands Chinese mitten crabs have already been recorded in all provinces with the highest abundance in the coastal provinces of Groningen, Friesland, Noord-Holland, Zuid-Holland and Zeeland. In general the numbers become lower with increasing distance from the sea and increasing numbers of migration barriers. In polders the amount of river water is an important factor determining the abundance of Chinese mitten crabs (K. Burger, pers. comm.).

Dunes, bogs and heathlands in The Netherlands are not likely to be colonised due to lack of connectivity. Furthermore, waters in bogs and heathlands often have a pH lower than 5.5, which is too low for the survival of large crustaceans.

The connectivity within the Dutch lowlands is very high and the eutrophic water systems within the lowlands offer very suitable conditions for the establishment of Chinese mitten crabs. Most streams and rivers in the Pleistocene area are also likely to be colonised, but densities are expected to remain lower than densities in the lowlands, because of the increasing migration distances from the sea.

The distribution of the Chinese mitten crab before 1990 presented in figure 7 is still a good indication for the current situation and expected distribution in the future (Soes *et al.*, 2007). Based on the data presented by Kamps (1937) the spread is relatively fast (fig. 6). After the colonization large parts of the Netherlands were colonized within five years.

As the Chinese mitten crab has a large potential area and is recorded to colonize these areas in a relatively short time frame the probability of spread is very high.

### 3.4 Endangered areas

Figure 13 presents the endangered areas for the Chinese mitten crab based on their current distribution and expected future distribution in The Netherlands (respectively § 2.3.3 and § 3.3). It can be concluded that the coastal provinces of Groningen, Friesland, Noord-Holland, Zuid-Holland and Zeeland and the larger inland river systems (especially in the so-called 'Rivierengebied') are most at risk as Chinese mitten crabs are most abundant in these areas.

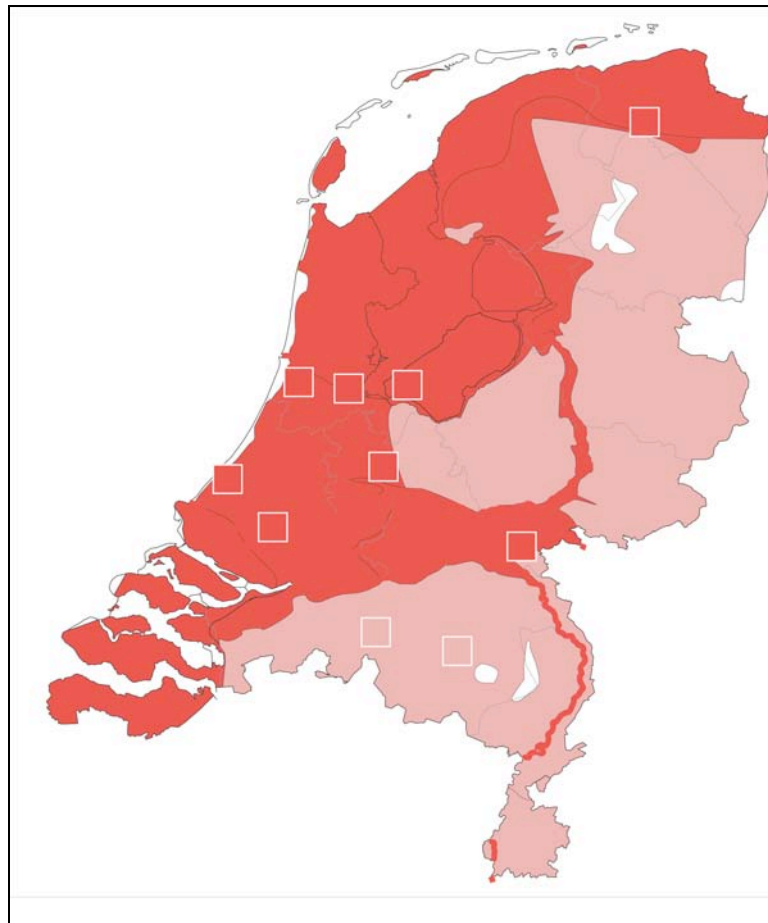


Figure 13 Endangered areas for the Chinese mitten crab in The Netherlands. (white: not endangered; pink: slightly endangered, red: highly endangered).

The 'danger' to these areas imposed by the presence of the crabs depends on the (potential) impacts the crabs can have in these areas. These impacts are described in the following paragraph (§ 3.5).

### 3.5 Impacts

#### Ecological impacts

Although many impacts have been described in the literature, hardly any of them have actually been observed or quantified in the field. The following ecological effects have been described:

##### Effects on chemical water quality

Burrowing activities and other activities that disturb soils can induce the release of phosphates and pollutants that are stored in the sediment (Smolder & Brouwer, 2006). Depending on the substances present in the sediment and their concentrations this may consequently affect the water quality (e.g. contribute to eutrophication) (Soes *et al.*,

2007). Crabs living in polluted waters can accumulate these components to harmful levels, which may be transferred to predators that consume the crab (Hymanson *et al.*, 1999), like mammals, birds and fish (§2.4.5).

Nutrients might also be released from the sediment due to increased fragmentation of dead plant material (detritus) resulting in an increased turnover of nutrients as well as increased aeration of underwater sediments. Because decomposition rate of plant material increases in the presence of Chinese mitten crabs, peat accumulation might be reduced or prevented.

Burrowing activities can also reduce the water clarity negatively impacting the development and growth of aquatic plants (Smolder & Brouwer, 2006).

Although impact of the Chinese mitten crab on water quality is likely no statement on the extent of this can be made due to data deficiency.

#### Predation on resident flora and fauna species

Chinese mitten crabs are omnivorous and opportunistic and feed on almost everything they can get (§2.4.4.). Therefore they have the potential to have an impact on resident flora and fauna species (Rogers, 2000), including species such as *Anisus vorticulus* (Natura 2000) and *Mercuria confusa* (highly endangered) and *Pseudanodonta complanata* (endangered). Regularly predation on *Dreissena sp.* and especially fish eggs are mentioned as possible negative effects (e.g. Anonymous, 2009). No data supporting these effects are published yet.

#### Competition with native species

Freshwater crabs are known as strong competitors of crayfish (Lukhaup, 2003). As the only native crayfish, the noble crayfish (*Astacus astacus*), is close to extinction and as recovery in the habitats the Chinese mitten crab occupies is most unlikely due to the presence of crayfish plague it is not expected that the Chinese mitten crab will have impact on the noble crayfish (Soes & Koese, 2010).

#### Transfer of diseases by functioning as a secondary host

The Chinese mitten crab can function as a secondary host for the Asian lung fluke (*Paragonimus westermani*), which that can cause diseases in humans or animals that become infected with the parasite (Yang *et al.*, 2000). In The Netherlands this parasite is not expected to be able to establish itself as its primary hosts (freshwater snails of the families Thiaridae and Pleuroceridae) are rarely found and the probability of establishment of these hosts in Dutch waters is small because of their low tolerance to low water temperatures (Gittenberger *et al.*, 1998; Bruyne *et al.*, 2003; Vaate *et al.*, 1994; Soes, personal observation).

#### **Interference with goals of the Water Framework Directive (WFD) and/or Natura 2000**

In the Water Framework Directive goals have been identified for both the water quality and the ecological values present in different water systems. In the Natura 2000 goals

have been identified for habitats and birds. Ecological effects of the Chinese mitten crab could interfere with these goals especially when high densities occur in a particular water system. Examples of specific goals of the WFD and/or Natura 2000 that could be affected by the Chinese mitten crab are presented in table 1.

Table 1 Examples of WFD and Natura 2000 goals that could be affected by the Chinese mitten crab

Goals	Possible impact of Chinese mitten crab
Improvement of the growth and development of aquatic plants	-Predation of plants by crabs. -Reduction of the water clarity caused by burrowing activities of crabs.
Stimulation of the population of mussels (e.g. <i>Dreissena spp.</i> ) as a food source for birds	-Predation of mussels by crabs.
Maintaining or stimulating the growth of populations of a specific bird species	-Toxication of birds caused by accumulation of substances in crabs that are consumed by birds (bioaccumulation).
Improvement of the water quality	-Release of phosphates and pollutants stored in the sediment caused by burrowing activities of crabs can lead to a decrease of the water quality.
Realisation of nature-friendly banks	-Erosion of banks caused by the creation of burrows of crabs. -Interference with the development of plant -, macrofauna or fish species due to predation by crabs.
Improvement of the development of macrofauna and/or fish communities	-Predation of macrofauna and fish species by crabs. -Habitat disturbance due to burrowing activities of crabs.

## Economic impacts

### Negative and positive impacts on commercial fisheries

The presence of Chinese mitten crab can have both negative and positive impacts on commercial fishermen. They can cause damage to commercial fishermen who use fish traps by:

- damaging fishing gear. Damage to fykes can be prevented by using fykes made from polyethylene instead of the traditional material nylon, but these fykes are more expensive and it is suggested that they are less suitable to catch eels than the traditional ones (Huver & Smit, 2005).
- consuming (part of) the fish caught in traps. Fish that have partly been eaten or damaged by crabs cannot be sold for consumption meaning loss of income for the fishermen.
- extending the handling time to sort fish from crabs. Because of the extended handling time fishermen have to deploy less fykes than usually to be able to empty them in the same time period (Kamps, 1937).

- stealing bait. When bait is removed by crabs, fish are not attracted anymore.

A positive effect of the presence of the crabs is the interest of humans to use them for consumption. Commercial fishermen can sell them in The Netherlands, but most of the crabs are exported to Asian restaurants in the City of Antwerpen, Paris and Italy and some to the Czech Republic (Leijzer *et al.*, 2007). In Den Oever (a fish auction in The Netherlands) the following increase was seen in the amount of Chinese mitten crabs offered for auction between 2003 and 2006 (Leijzer *et al.*, 2007; 2008):

- 2003: 11 tonnes with an average sale price of 3,43 euro per kg.
- 2004: 22 tonnes with an average sale price of 3,68 euro per kg.
- 2005: 32 tonnes with an average sale price of 4,03 euro per kg.
- 2006: 12 tonnes with an average sale price of 6,23 euro per kg.

Despite this increase the price stays relatively low because of the very variable amount of crabs offered for auction (T. Bult, pers. comm.). Another concern is the accumulation of toxic substances in Chinese mitten crabs making them not suitable for consumption by humans. For example, crabs collected in 1995 and 1998 from the Elbe and the Havel in Germany exceeded the standards for HCB, HCH, DDT and Methoxichloride (Fladung, 2000) and crabs collected in Hong Kong have exceeded the standards for heavy metals (Ong Che & Cheung, 1998).

In Germany it was estimated that 60 commercial fishermen were adversely affected by Chinese mitten crabs during the period 1994-2004, with an estimated cost of 8.4 million euro (14,000 euro per fisherman annually). The value of crabs sold in the same period was estimated between 3 and 4.5 million euro (Gollasch, 2006). No such economic analysis has yet been performed in The Netherlands, but as eel fisheries is more effected and of greater economic importance in the Netherlands compared to Germany the negative economic impact is expected to be higher in the Netherlands (Dekker, 2004).

In conclusion the economic impact of the Chinese mitten crab on inland fisheries is expected to be high.

#### Erosion of banks caused by burrowing activities of the Chinese mitten crab

Chinese mitten crabs create burrows in the banks varying in length from approximately 20 to 80 cm and in diameter from 2 to 12 cm. Most of these burrows are created in banks consisting of soft sediments by juvenile crabs that use burrows for shelter during moulting. The form of a burrow is generally a straight line, but when obstacles (like stones) are present in the banks or when different burrows become connected to each other the form of burrows becomes more complex (Rudnick *et al.*, 2005; Peters & Panning, 1933, Adema, 1991).

Creation of these burrows results in sediment removal making a bank more susceptible to erosion. This effect has for example been observed in the South Francisco Bay (Rudnick *et al.* 2005) and Germany (Peter & Panning, 1933). In the San Francisco Bay, where densities of burrows of the Chinese mitten crab ranged between 2-18 per m<sup>2</sup> in

1995/1996 and 18-39 per m<sup>2</sup> in 1999, it was estimated that the sediment removal caused by burrowing activities of the Chinese mitten crab ranged between 564 cm<sup>3</sup> to 2,538 cm<sup>3</sup> in 1995/1996 and 2,538 cm<sup>3</sup> to 5,499 cm<sup>3</sup> per m<sup>3</sup> bank area in 1999 Rudnick *et al.* (2000).

There appears to be evidence of mitten crab burrows along some unprotected riverbanks of the Thames especially on Chiswick Eyot and along the banks of Syon Park, Middlesex. The *Phragmites* bed on Chiswick Eyot has been particularly eroded away in recent years by the probable burrowing behavior of crabs. According to C. Dutton, Environment Agency (in lit.) the bank at Chiswick Eyot has receded circa six metres.

The consequences of a breakdown of a bank depend on the function of the particular bank (e.g. protection against flooding, directing the water flow) and the land use adjacent to the water system (e.g. agriculture, nature reserve), but could include alteration of the course of a waterway (Rudnick *et al.*, 2003) or damage to agricultural crops (Chinese Mitten Crab Working Group, 2003).

After 80 years of Chinese mitten crab populations no serious damage created due to burrowing activities has been reported in the Netherlands (Adema, pers. com.). The risk of damage at a larger scale is because this lack of evidence expected to be low, although it is advisable to stay alert as moderate impact has been reported from the Thames and California.

#### Damage to agricultural crops

In China and Korea crabs have been reported to cause huge damage to rice crops by feeding on young rice shoots (Ng, 1999). So far no reports are known from crabs causing damage to agricultural crops in Europe.

#### Blocking water intake systems of industrial enterprises

Chinese mitten crabs can block the cooling systems of power plants or other industrial activities (Hieb, 1998). Crabs can enter cooling water intakes during their downstream migration, blocking the plumbing and drastically reducing water flows. Periodic back flushing is then required to prevent overheating of the systems (Hieb, 1998).

This problem is also reported in The Netherlands from sewage water treatment plants, for example in the village of Franeker (Huver & Smit, 2005) and the village of Veendam (Peter Schollema, pers. comm.). The problem the village of Franeker was solved by fitting a grid in front of the pipes blocking the entrance of the pipes for Chinese mitten crabs (Huver & Smit, 2005).

High numbers of Chinese mitten crabs in cooling water intakes have also been reported from other Dutch plants. Well-known examples are the power plants from Nijmegen and Velsen (Soes *et al.*, 2007). The presence of these high numbers of crabs results in financial costs in their handling and destruction. No figures, however, are publicly available.

## **Social impacts**

### Interference with recreational fishing

Chinese mitten crabs interfere with recreational fishermen in The Netherlands through the stealing of bait (Peters & Panning, 1933; Kamps, 1937). This interference can occur with any type of recreational fishing as the crabs are omnivorous and will feed on whatever sort of bait is used (e.g. fish, cheese, bread). Due to the crabs' nocturnal behaviour, fishermen trying to catch common carp, pike, perch and eel during the night are particularly affected (Soes *et al.*, 2007). Many fishermen in California reported abandoning traditional fishing areas to avoid interference with the Chinese mitten crab (Hieb, 1998).

### Crabs in urban areas

During their migration crabs are reported in urban areas like backyards, playgrounds and even inside houses and/or apartments. In some cases this raises some concern and animal ambulances or police might get involved.



## 4 Risk Management

### 4.1 Prevention of entry

Support measures to ensure the success of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (2004) will come too late for The Netherlands with an already established Chinese mitten crab population, but is of great importance for the prevention of spread to countries with no Chinese mitten crab populations. This convention stipulates that all ships carrying ballast water must install a treatment system by 2016. As of October 2008, 16 Parties representing 14,24% of the world's merchant shipping tonnage have ratified the convention (Kelly & Maguire, 2009), including The Netherlands. Recent managing practices to control the spread of invasive species through ballast water include open ocean ballast water exchange (e.g. requirement of federal regulations in the U.S. before arriving in the ports of California, Oregon and Washington (Chinese Mitten Crab Working Group, 2003)), but filtration of ballast water may be more appropriate (Hülsmann & Galil, 2001).

### 4.2 Prevention of spread

Preventing further spread of the Chinese mitten crab in The Netherlands will be difficult because of the many different pathways that can be used by crabs to invade new areas (§ 3.1 probability of entry), together with the already high abundance in especially the coastal provinces and larger inland rivers and streams. Other difficulties to prevent its spread are the high reproductive rate of this species, its wide range of physiological tolerances (e.g. temperature and salinity) and its ability to migrate over land. Furthermore, measurements preventing migration of the Chinese mitten crab will also prevent the migration of fish species.

During Chinese mitten crab fishing large numbers of crabs that are too small for selling are caught. It has been suggested to stock these small crabs in 'polders' too allow them to grow to a commercial size (T. Bult, pers. comm.). This will increase the dispersion of the Chinese mitten crab. Under current legislation such experiments can be legally performed. To prevent further spread a change in legislation forbidding the stocking of Chinese mitten crabs can be considered.

Support measures to ensure the success of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (2004) will come too late for The Netherlands with an already established Chinese mitten crab population, but is of great importance for the prevention of spread to countries with no Chinese mitten crab populations. This convention stipulates that all ships carrying ballast water must install a treatment system by 2016. As of October 2008, 16 Parties representing 14,24% of the world's merchant shipping tonnage have ratified the convention (Kelly & Maguire, 2009), including The Netherlands. Recent managing practices to control the spread of

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### **4.3 Eradication and physical control methods**

In countries where Chinese mitten crabs have established populations researchers have experimented with a variety of physical controls to reduce Chinese mitten crab populations, but no cases of fully successful eradication have been reported. Complete eradication in The Netherlands is also unlikely, because of its wide distribution and high abundance, especially in coastal provinces and larger inland rivers and streams.

### **4.4 Eradication and physical control methods**

The following physical control methods have been applied to reduce established populations of the Chinese mitten crab.

#### (Selective) fishing and trapping

In several countries (including The Netherlands and Germany) millions of crabs are caught annually using a variety of commercial fish traps and are commercially sold (Leijzer *et al.*, 2007; 2009). These fisheries are most successful during migration events and at locations where a river is contained by a regulatory structure (e.g. dam, fish migration facility). In Germany for example, traps placed on the upstream side of dams catch juvenile crabs as they migrate upstream. In the U.S. the feasibility of capturing adult crabs via a diversion and pitfall trap during fall downstream migration was evaluated. Success of this method appeared to be very high with an estimated 11,000 crabs captured in one small creek during a six-week period, with 85% of the crabs caught in less than three weeks (Chinese Mitten Crab Working Group, 2003).

The impact of commercial fishing on the population development of the Chinese mitten crab has not yet been evaluated. In the Thames a research on fisheries as a control method for Chinese mitten crab is ongoing. First results might be expected in 2010 (Engelhaupt, 2009). These results might also shed light on the possibilities of this method to reduce the number of crabs in the Netherlands and at the same time to improve the trade for consumption (§3.5.2). An evaluation programme should be carried out to determine the sustainability and potential of a Chinese mitten crab fishery.

#### Installation of travelling screen and trash racks

This method has been applied in Germany and has the potential to drastically restrict a large proportion of the mitten crab population during migration events. The method is shown to be most effective if done at locations where a river or stream is contained by a regulatory structure (e.g., dam, fish facility) (Peters & Panning, 1933).

#### Installation of electrical screens

In order to prevent the migration of the crab up rivers in Germany electrical screens were installed on the river bottom during the 1930-40s and pulses 30-40 times per minute were used to disable and kill the crabs. However, this method of control met with little success (McEnnulty *et al.*, 2001).



# 5 Conclusions

## 5.1 Conclusions

### Conclusions probability of entry

- The Chinese mitten crab was first reported in The Netherlands in 1931 and is nowadays very common throughout The Netherlands (see §2.3.3).
- Crabs can easily be introduced via rivers from the neighbouring countries Germany and Belgium (e.g. transport of larvae by currents, dispersal of adults and juveniles) where they also occur in high densities.
- Crabs can also be introduced in The Netherlands via ballast water in ships from their native range (see §2.3.1) or countries where they have been able to establish exotic populations (see §2.3.2).
- Other introduction pathways in The Netherlands include (intended and unintended) transport by humans for example introduction for research - or commercial (trade for consumption) purposes and escape or release from public aquaria.

### Conclusions probability of establishment

- Since its introduction in The Netherlands in early 1930s the Chinese mitten crab has been able to invade all provinces in The Netherlands and is now established and widespread throughout The Netherlands. In some areas densities increased during some years to such high levels that they have been reported as plagues.
- The Chinese mitten crab has already established populations in The Netherlands.

### Conclusions probability of further spread

- Chinese mitten crabs have already been recorded in all provinces with the highest abundance in the coastal provinces of Groningen, Friesland, Noord-Holland, Zuid-Holland and Zeeland.
- In general the numbers become lower with increasing distance from the sea and increasing numbers of migration barriers.
- In polders the amount of river water is an important factor determining the abundance of Chinese mitten crabs (K. Burger, pers. comm.).
- Dunes, bogs and heathlands in The Netherlands are not likely to be colonised due to lack of connectivity. Furthermore, waters in bogs and heathlands often have a pH lower than 5.5, which is too low for the survival of large crustaceans.
- The connectivity within the Dutch lowlands is very high and the eutrophic water systems within the lowlands offer very suitable conditions for the establishment of Chinese mitten crabs.
- Most streams and rivers in the Pleistocene area are also likely to be colonised, but densities are expected to remain lower than densities in the lowlands, because of the increasing migration distances from the sea.
- The distribution rate is high based in the quick colonization of the Netherlands.

### **Conclusions endangered areas**

- The coastal provinces of Groningen, Friesland, Noord-Holland, Zuid-Holland and Zeeland and the larger inland river systems (especially in the so-called 'Rivierengebied') are most at risk as Chinese mitten crabs are most abundant in these areas.
- The 'danger' to these areas imposed by the presence of the crabs depends on the (potential) impacts the crabs can have in these areas.

### **Conclusions impacts**

Many impacts have been described in the literature, but few of them have actually been observed or quantified in the field.

#### Ecological impacts

- Burrowing activities of Chinese mitten crabs can induce the release of phosphates and pollutants that are stored in the sediment. Depending on the substances present in the sediment and their concentrations this may consequently affect the water quality.
- Burrowing activities can reduce the water clarity negatively impacting the development and growth of aquatic plants.
- Crabs living in polluted waters can accumulate toxic substances to harmful levels, which may be transferred to predators that consume the crab, like mammals, birds and fish (§2.4.5).
- Because of their omnivorous and opportunistic feeding habits Chinese mitten crabs can have an impact on resident flora and fauna species in The Netherlands, some of which might be species from Red List or Natura 2000. This includes examples like aquatic plant species, mussels, insects and their larvae (especially *Chironomus*-larvae), *Gammaridae*, various snail species, Bryozoa, freshwater polyps (*Hydra*), various worms, (dead) fish and freshwater crayfish.
- The Chinese mitten crab can function as a secondary host for the Asian lung fluke (*Paragonimus westermani*), but the probability of establishment of this parasite in Dutch waters is small, because of the low tolerance to low water temperatures of its primary host.

Because of these ecological impacts the Chinese mitten crab can interfere with goals identified under the Water Framework Directive and the Nature 2000.

#### Economic impacts

- Burrowing activities of the Chinese mitten crab can cause erosion of riverbanks. The consequences of a breakdown of a bank depend on the function of the particular bank (e.g. protection against flooding, directing the water flow) and the land use adjacent to the water system (e.g. agriculture, nature reserve), but could include alteration of the course of a waterway or damage to agricultural crops.

- Chinese mitten crab can negatively impact commercial fishermen by damaging fishing gear, consuming (part of) the fish caught in the traps, extending the handling time to sort the fish from the crabs and by stealing bait.
- The crabs can be sold for consumption generating income for commercial fishermen, but the very variable amount of crabs offered for auction keeps the price relatively low and accumulation of toxic substances in crabs (bioaccumulation) could pose a health risk for humans.
- In China and Korea crabs have been reported to cause damage to rice crops by feeding on young rice shoots, but so far no reports are known from crabs causing damage to agricultural crops in The Netherlands.
- Chinese mitten crabs can block cooling water and other water intake systems of industrial companies.

#### Social impacts

- Chinese mitten crabs interfere with recreational fishermen through bait stealing. To avoid interference fishermen have to abandon their traditional fishing grounds.
- During their migration crabs are reported in urban areas like backyards, playgrounds and even inside houses or apartments.

#### **Conclusions prevention of entry**

- Support measures to ensure the success of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (2004) will come too late for The Netherlands with an already established Chinese mitten crab population, but are of great importance for the prevention of spread to countries with no Chinese mitten crab populations.

#### **Conclusions prevention of spread**

- Preventing further spread of the Chinese mitten crab in The Netherlands will be difficult because of the many different pathways that can be used by crabs to invade new areas, together with the already high abundance in especially the coastal provinces and larger inland rivers and streams, the high reproductive rate of this species, its wide range of physiological tolerances and its ability to migrate over land.
- In preventing further spread a change in legislation forbidding the stocking of Chinese mitten crabs can be considered.

#### **Conclusions eradication and control methods**

- In countries where Chinese mitten crabs have established populations researchers have experimented with a variety of physical controls to reduce Chinese mitten crab populations, but no cases of fully successful eradication have been reported. Complete eradication in The Netherlands is also unlikely.
- Physical control methods to reduce the number of crabs in The Netherlands could include:
  - (Selective) fishing and trapping during migration events at locations where a river or stream is contained by a regulatory structure (e.g. dam,

fish migration facility); A feasibility study should be carried out to determine the sustainability and potential of a commercial fishery to reduce the number of Chinese mitten crabs in The Netherlands;

- Installation of travelling screens and trash racks at locations at the same locations as described above.



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