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Research article

Invasion routes, current and historical distribution of the Chinese mitten crab (*Eriocheir sinensis* H. Milne Edwards, 1853) in Sweden

Marcus K. Drotz[1*], Matz Berggren[2], Stefan Lundberg[3], Kennet Lundin[4] and Ted von Proschwitz[4]

[1]*Lake Vänern Museum of Natural and Cultural History, Framnäsvägen 2, 53154 Lidköping vid Vänern, Sweden*
[2]*Inst. Marine Ecology-Kristineberg, Göteborg University, Kristineberg 566, SE-450 34 Fiskebäckskil, Sweden*
[3]*Swedish Museum of Natural History, P.O. Box 50007, SE-104 05 Stockholm, Sweden*
[4]*Göteborg Natural History Museum, Slottsskogen, Box 7283, SE-402 35 Göteborg, Sweden*

E-mail: marcus.drotz@lidkoping.se (MKD), matz.berggren@marecol.gu.se (MB), stefan.lundberg@nrm.se (SL), ted.v.proschwitz@vgregion.se (VPT), kennet.lundin@vgregion.se (KL)
**Corresponding author*

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Abstract

Single specimens of the Chinese mitten crab, *Eriocheir sinensis* H. Milne Edwards, 1853, have been regularly reported along the western and eastern coasts of Sweden since the 1930´s. The crab has most likely been brought from overseas via the transfer of ship's ballast water or secondarily introduced from its key European distribution areas. Since 2001 a sharp increase in the occurrence of the mitten crab has been noticed in Swedish inland waters, but the dispersal routes and distribution of the species into Sweden remain poorly known. Here we document the current and historical distribution of the Chinese mitten crab in Sweden and assess possible invasion routes. A special focus is put on the historical occurrence of crabs in Lake Vänern, which empties into the Skagerrak/North Sea and Lake Mälaren, which connects to the Baltic Sea. The existing time series available for the mitten crab from the two lakes shows a large variation in dispersal pattern between different areas within each lake. In order to detect and monitor outbreaks of the mitten crab in Sweden, an internet based reporting system was created in 2007. Museum collections and reports from the general public throughout Sweden were compared with the known occurrence of mitten crabs in Lake Vänern and Lake Mälaren. During the study, the web-based reporting system was not advertised and the general public did not get paid for reporting the information. Population densities of the crab occurred "in peaks" and unevenly over the last decade in both lakes, suggesting a pulse invasion instead of a constant supply by migration. Significant difference in male and female occurrence together with few transport possibilities between lakes suggests different invasion routes for the crabs. Reports from the general public throughout Sweden coincide with the observations from local fishermen in Lake Mälaren and Lake Vänern. Data on occurrence and abundance are discussed in relation to a potential reproduction area on the western coast of Sweden.

Key words: Crustacea, Brachyura, Lake Vänern, Lake Mälaren, transport routes, ballast water, early warning system

Introduction

The catadromous Chinese mitten crab, *Eriocheir sinensis* H. Milne Edwards, 1853 (Crustacea: Brachyura: Varunidae) is well known for its astounding invasion capacity across the world. This crab species was first reported outside its native spawning areas in China from the River Aller in northern Germany in 1912 (Panning and Peters 1932; Lönnberg 1932; Hymanson et al. 1999; Veldhuizen et al. 1999). This long distance dispersal outside its natural geographical area most probably occurred by transport of zoea or megalopa stages in the ballast water of merchant vessels. Because of the mesh size of the water intake filter which protects the ship's ballast pumps from larger object, the adult crabs are less likely to be pumped onboard without damage. Since this first European report, the crab is now reported from the North Sea to Europe's southern Atlantic coast including Great Britain and Ireland as well as the Mediterranean Sea to Turkey where single specimens have been found (Lönnberg 1932; Hanström 1937; Kamps 1937; Peters 1938; Hoeslandt 1948; Cabral and Costa 1999; Herborg et al. 2003; Czerniejewski et al. 2003; Rudnick et al. 2003; Herborg et al. 2005; Ojaveer et al. 2007). In the Baltic Sea, the mitten crab has been sparsely reported during the last eight decades (Ojaveer et al. 2007). The lack of an established population within this area is attributed the low salinity within the Baltic Sea

in combination with low surface water temperatures (Anger 1991, 2003). However, a decade ago the number of reported observations within this region started to increase, and the crab has now been reported as far north as the northernmost part of the Bay of Bothnia in the Haparanda archipelago (Ojaveer et al. 2007 and web-reports from fishermen in the area). Many authors (Panov 2006; Ojaveer et al. 2007; Shakirova et al. 2007) explained this as a consequence of the increased number of crabs in estuaries in the north-western part of Central Europe, which presumably serves as the species northern breeding area. The number of observations is also increasing along the coastal areas and larger coastal connected lakes within Sweden, especially in Lake Vänern, which is the third largest lake in Europe and which empties into the Skagerrak/North Sea at the Göteborg (Gothenburg) estuary (Lundin et al. 2007, Figure 1). An increase has also been reported from Lake Mälaren. The observations from Lake Vänern are more disturbing however, since the salinity and annual surface water temperature in Skagerrak are in the lower reproductive potential range for the species (Anger 1991), in contrast to Lake Mälaren which empties into the Baltic Sea.

Very little information is known about the distribution, population structure and movement pattern of the mitten crab in Sweden. The general public there is supportive in providing information of changes in distribution and abundance of the crab. In addition, knowledge of the significant invasion possibilities to different harbours by ship transfer routes is important along with information on the population densities of the known self-sustaining European mitten crab populations (Herborg et al. 2007a). Combination of these data is vital in order to understand and monitor the distribution of the mitten crab. The potential of a self-sustaining population on the Swedish west coast and the knowledge of its potential widespread impact, not only to Lake Vänern but to the entire Baltic Sea region, make the Swedish distribution of mitten crab a very important issue to study and monitor (Ojaveer et al. 2007).

The aim of the present study included four specific objectives to: (1) quantitatively describe the reported catch history and the current distribution of the Chinese mitten crab in Sweden, (2) evaluate the extent to which observations from the general public can contribute to our understanding of the current distribution of the mitten crab in Sweden, (3) analyse the possible invasion routes into Sweden from self-sustaining crab populations within Europe, and (4) discuss the possibility of a new self-sustaining mitten crab population along the west coast of Sweden.

Materials and methods

In order to quantify the historical and current distribution of the Chinese mitten crab in Sweden, we first screened the collections in natural history museums of Sweden. Reports of findings from the general public have been collected and occasionally specimens have been sent to museums (Stockholm and Göteborg mainly) sparingly until the mid 1990 when findings suddenly went up. A total of four collections of records and specimens were found including Chinese mitten crabs in Sweden. The oldest record is not labelled with a date but is assumed to be from the 19th century. To assess the efficiency and functionality of the general public as an early warning system, we created an internet based registration portal to collect observations from the general public in Sweden (http://www.nrm.se/ullhandskrabba). This first ever public registration portal for the Chinese mitten crab in Sweden was launched in Spring 2007. The registration portal was not advertised and reports were given on a voluntary basis. The catch history of crabs in Lake Vänern and Lake Mälaren was compiled from fishermen's private reports of their by-catch since mid 1990. Local fishermen utilise large stationary fish trap nets, with pot sizes of 10 to 15 m^3 connected to leader arms of several hundred meters in length. These traps are routinely checked every second day. The fishing effort in terms of location within the lake, seasonal variation in effort, and type of gear remained constant during the last decade within Lake Mälaren and Lake Vänern. The number of fish traps in Lake Vänern did however increase in year 2004 and were more evenly spread along the southern shores of Kinneviken. Commonly, a fisherman has five to ten fish traps.

Four regions, two from each lake, were studied regarding the routes of freight ships. In three of these four regions, we were able to collect abundance data of mitten crabs caught in fishing gear. In Lake Mälaren, the first area is Bay of Galten, located in the most westernly part of the lake close to the city and harbour of Köping. The second area lies in the central region near the island of Ängsholmen and is close to both the city and harbour of Västerås.

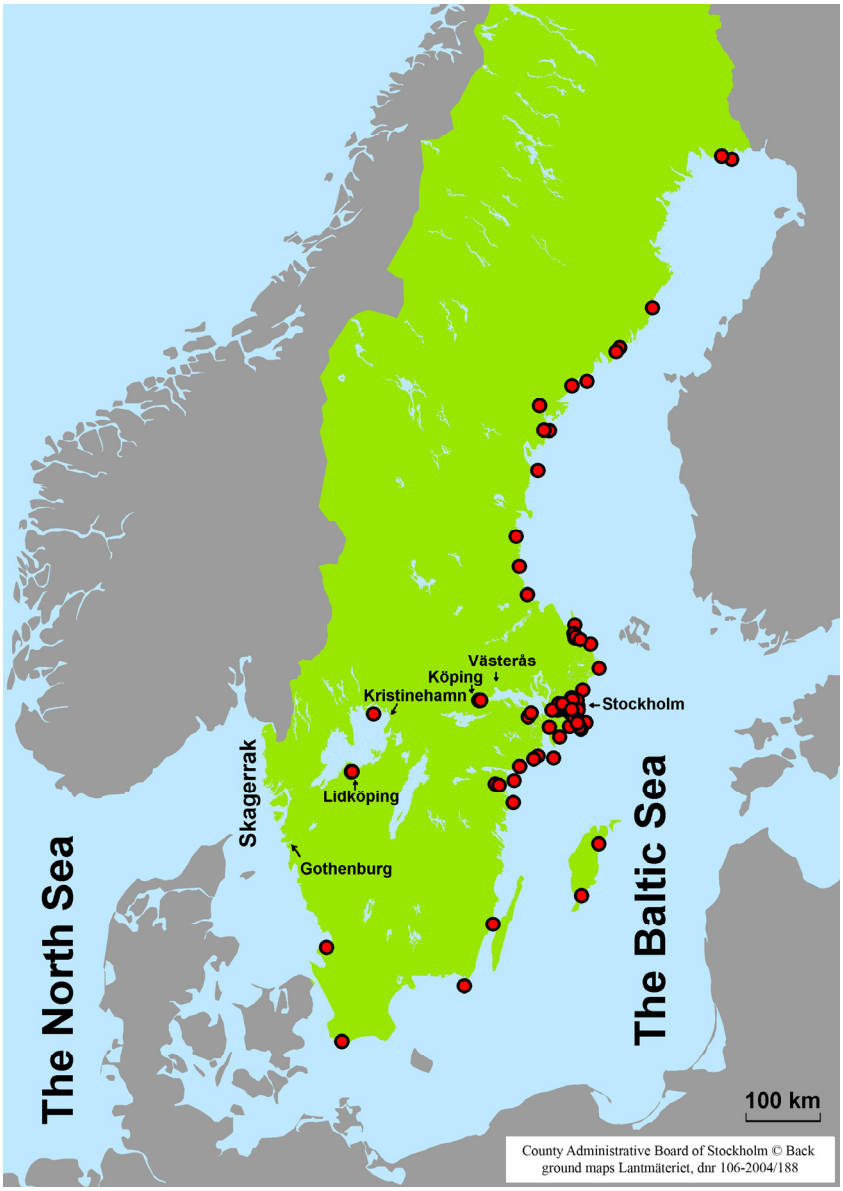

Figure 1. The locations of the Chinese mitten crab (*Eriocheir sinensis*) reports in Sweden from 2007 until 2009 (see Appendix 1). One dot may represent more than one occurrence. Harbors in Lake Vänern: Cities of Kristinehamn, Lidköping, and in Lake Mälaren: Cities of Köping and Västerås (marked with arrows).

In Lake Vänern, the first area is the Bay of Kinneviken, which is near the city and harbour of Lidköping in the southeastern part of the lake. The second area in Vänern is located outside the city and harbour of Kristinehamn in the northeast (Figure 1). Caught specimens were stored in small-submerged cages by the local fisherman prior to their transport to the Lake Vänern Museum of Natural and Cultural History. At the museum each crab were sexed and the carapace length (CL) and width (CW) measured to the nearest 0.5 mm by use of a calliper as described by Czerniejewski and co-workers (2003). Data for the shipping routes from harbours of self-sustaining mitten crab populations in Europe to Lake Vänern and Lake Mälaren were obtained from the National Statistics Office of Sweden (SCB) (http://www.scb.se).

Results

Historical and present day records

A total of 40 Chinese mitten crabs were found within the natural history museums' collections

along with records of 38 additional crabs from fishermen around Sweden. The first mitten crab to be reported in Sweden was found in the Bay of Bråviken (a bay of the Baltic Sea), Province of Östergötland, Eastern Sweden, in 1932 (Hanström 1937). Crab specimens were subsequently observed throughout Sweden during the following decades. In 1936 the mitten crab was found in Lake Mälaren and in 1954 in Lake Vänern (Table 1). Thereafter observations became rare and only a few single specimens were officially reported. During the 1990´s, the observations became more frequent in Lake Mälaren and at the end of that decade local fishermen reported large numbers of crabs in both the central and western parts of the lake. In the following years, the number of observations seem to fluctuate and large differences in abundance were reported between the two areas, especially during 2001-2002 and in 2006 (Figure 2). In Lake Vänern, mitten crabs started to increase later and reached their first clear peak in 2005 in the Bay of Kinneviken. During the same time period, large numbers of crabs (up to several hundred) were reported from the northern part of the lake near Kristinehamn. The numbers then started to decrease and the crab was reported occasionally from the Bay of Kinneviken in 2009. However, single specimens were found throughout the lake during the same year. Today almost 250 reports of observed or caught mitten crabs have been compiled covering the entire Swedish coast (Figure 1, Appendix 1, Lundin et al. 2007).

Size of the crabs caught in Lake Vänern and Mälaren was measured during August to November 2007 only, this is due to the paucity of samples in successive years. Out of a total number of 61 crabs captured, 34 specimens were found in the central parts of Lake Mälaren and 17 in Bay of Galten. The remaining 10 specimens were captured in Bay of Kinneviken, Lake Vänern. The size of these crabs varied between 49.0 to 90.9 mm in CW and 45.5 to 80.7 mm in CL for males and 55.5 to 82.8 and 52.7 to 79.2 mm respectively for females (Table 2). Crabs from both lakes showed no significant differences in carapace width (*ANOVA:* $P = 0.24$ and 0.11, males and females, respectively) or length (*ANOVA:* $P = 0.09$ and 0.09, males and females, respectively). The males were significantly more abundant than the females within Lake Vänern ($P < 0.01$, *G-test*) compared to Lake Mälaren where both sexes were equally abundant ($P = 0.61$, *G-test*). The smallest specimen found in Sweden was a male with a carapace width (CW) of 32 mm and collected in the Göta Älv near the city of Göteborg.

Using observations from the general public as an early warning system

The use of an internet based registration portal to collect observations from the general public across Sweden started in May 2007 and the first record was registered on May 10th of that year. During subsequent years, the general public (which include non professional net fishing and anglers) registered annually around 30 reports across Sweden (Figure 3). This is a remarkable increase in the number of crab reports from previous years. Observations from the general public coming from all areas across Sweden coincide in time of year to the observations from the local fishermen in Lake Mälaren and Lake Vänern (Figure 4).

Transport routes

Shipping data for the 2004-2006 time period obtained from the Swedish Transport Agency show that 30–42% of ships arriving in Lake Vänern and 24–43% in Lake Mälaren came from harbours known to have self-sustaining mitten crab populations in Germany, Great Britain and the Netherlands. Ships also arrived from Poland, in particular the Police and Szczecin region, where a known population of mitten Crabs also exists. In the harbour of Kristinehamn (Lake Vänern) ships arrive predominantly from Hull, Great Britain, where a mitten crab population is described in the Humber River Estuary (Table 3). On the other hand, ships going to the harbour in Lidköping (Lake Vänern) come most frequently from Rotterdam and Amsterdam in the Netherlands, where a mitten crab population is found in the Maas River Estuary. In Lake Mälaren the Västerås harbour receives ships from several harbours in Great Britain, Germany, the Netherlands and Poland, whereas ships arriving at Köping come mainly from the Netherlands and Poland.

Discussion

In recent literature the mitten crab in Lake Mälaren has been considered to belong to an established population based on the capture of more than ten specimens annually over five consecutive years (Herborg et al. 2007a). Because the salinity of the Baltic Sea is too low

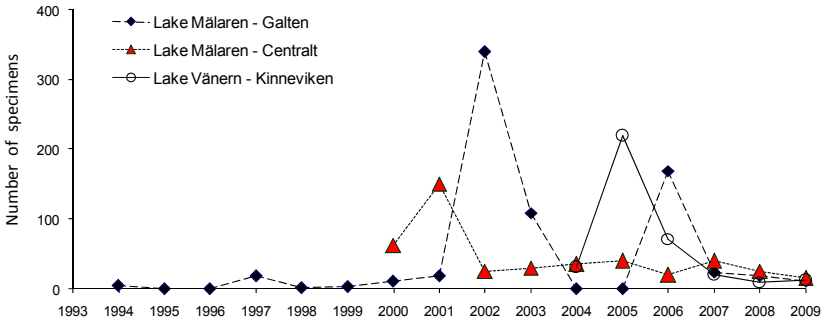

Figure 2. Yearly catch of the Chinese mitten crab, *Eriocheir sinensis*, based on the trap net fisheries in Lake Vänern and Lake Mälaren, during 1994 to 2009. Lake Mälaren: central part (···▲···). Lake Mälaren, western part (---♦---) and in Lake Vänern, Bay of Kinneviken (—○—).

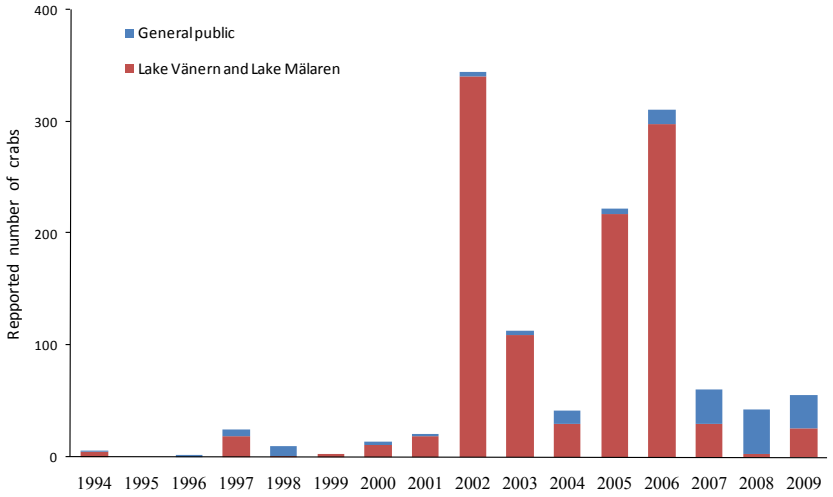

Figure 3. Annual reports of the Chinese mitten crab, *Eriocheir sinensis* in Sweden between 1994 and 2009. Reports from the general public (■), from fishermen in Lake Vänern and Lake Mälaren (■).

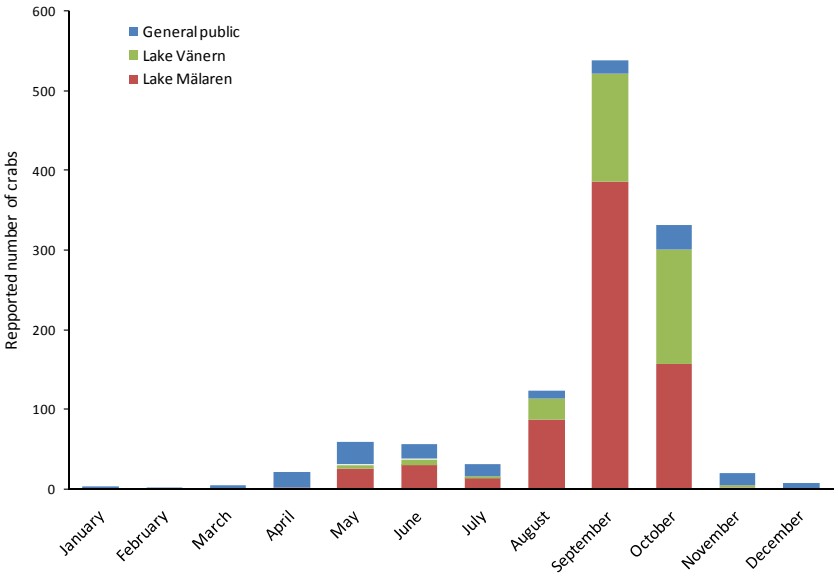

Figure 4. Monthly distribution of the Chinese mitten crab, *Eriocheir sinensis*, reports in Sweden. Reports from the general public between 1900 and 2009 (■), from fishermen in Lake Vänern between 2004 and 2009 (■) and Lake Mälaren between 1990 and 2009 (■).

Table 1. First historical records of Chinese mitten crab, *Eriocheir sinensis*, in various geographical regions in Sweden.

Year	First record	Locality	References
1932	Sweden	Östergötland: Bay of Bråviken.	Stolt (1934), Hanström (1934)
1934	Southernmost Sweden	Skåne: Åhus.	Hanström (1934)
1934	Southern part of the Gulf of Bothnia	Gästrikland: Island of Iggön	Anonymus (1934), Hanström (1934)
1934	Stockholm area	Nacka, Skurusundet; Bay of Ingaröfjärden; S. Djurgården	Lönnberg (1934), Hanström (1934)
1936	The Swedish west coast	Göteborg: Bay of Älvsborgsfjorden, Island St. Aspholmen	Jägerskiöld (1936)
1936	Inland fresh water	Lake Mälaren: Bay of Segeröfjärden, at Strängnäs	Lönnberg (1936)
1937	Chanel Göta kanal	Östergötland: Karlsborgs slussar	Lönnberg (1937)
1943	Central part of the Gulf of Bothnia	Västerbotten: SW of Skellefteå, Burvik	Ekblom (1944)
1946	Northenmost record	Norrbotten: Lule skärgård arkipelago, Islands of Långön and Sandgrunnan	Anonymus (1946), Enequist (1946)
1954	Lake Vänern	Västergötland: Lake Vänern, Bay of Vassbotten	Anonymus (1954), Fontain (1955)
1959	Northernmost inland record	Lake Glafsfjorden	Mathiasson (1961)

Table 2. Sexual distribution and morphological variation of the Chinese mitten crab, *Eriocheir sinensis*, in Lake Vänern and Lake Mälaren, based on the trap net fishing during August to November, 2007. Numbers of male and female specimens (N_M, N_F) measured and mean and standard deviations values of carapace width (CW) and carapace length (CL) are provided.

Lake	Area	N_M	Male		N_F	Female	
			CW	CL		CW	CL
Mälaren	Central	17	69.97 ± 1.60	65.73 ± 1.45	17	67.57 ± 1.48	64.30 ± 1.28
	Galten	10	70.90 ± 2.63	66.68 ± 2.13	7	68.81 ± 1.63	64.44 ± 1.47
Vänern	Kinneviken	9	65.20 ± 3.16	60.08 ± 2.97	1	-	-

Table 3. Distribution of ships from harbours with populations of the Chinese mitten crab, *Eriocheir sinensis* to the port of call in Lake Vänern and Lake Mälaren during the years 2004-2006. Ship transport routes are based on the reports from the National Statistics Office of Sweden (SCB). Established mitten crab populations are taken from Herborg et al. (2007a) and Czerniejewski and Wawrzyniak (2006).

Country	Population	Port of call			
		Vänern-Lidköping	Vänern-Kristinehamn	Mälaren-Köping	Mälaren-Västerås
Germany	Elbe R.	+	+		+
	Weser R.	+			
	Rhine R.				+
The Netherlands	Mass R.	+		+	+
	Schelde and Ems R.		+		
Poland	Odra R.	+		+	+
Great Britain	Humber R.		+		+

for successful reproduction and recruitment (Ojaveer et al. 2007), a proposed migration route is suggested from breeding areas in North Germany along canals into the Baltic Sea and then into Lake Mälaren in Sweden (Herborg et al. 2007a). No mitten crab observation has been reported along the final part of this route however. This proposed path implies a more or less constant migration of crabs into Lake Mälaren, a prediction for which we have no

evidence from the present study. Lake Mälaren and Lake Vänern both have a peak-wise occurrence of crabs, which would support evidence for repeated invasions (Figure 2). Indeed, sampling variability may induce bias in this time series of observations. However, local fishermen from both lakes tend to be conservative with the placement of their large fishing gear, *i.e.* trap nets. The traps are placed in the lakes shortly after the ice melts in April and are left in the water until October or November. Crabs caught earlier than 2006 were normally killed in the fishing boats, but in more recent years the fishermen stored crabs in smaller nets prior to transport to the Lake Vänern Museum of Natural and Cultural History.

Each observation thus represents a unique crab capture event. The fishing gear is selective and collects crabs larger than 30 mm in CW only. The positions of the trap nets within Lake Mälaren and Lake Vänern are in the direct vicinity of the region where ships start to pump out their ballast-water prior their arrival to the harbour. The large distance (95 km) between the two collecting areas in Lake Vänern minimizes the possibility that one ship could "spill" transporting crabs into both investigated regions. This could be a problem in Lake Mälaren where the distance between the collecting areas are 30 km, but the difference in crab abundance between the collecting areas within the lake does not support this (Figure 2).

As a consequence, it is of prime interest to identify and discriminate areas where mitten crab reproduction is established in contrast to regions where the occurrence of crabs is a consequence of (1) a supply-side effects by ship transport or (2) larval migration, or both (Czerniejewski and Wawrzyniak 2006; Ojaveer et al. 2007).

The difference between the harbours in Lake Vänern, according to ships arriving from multiple source areas in Europe, clearly implies that the lake could receive specimens from five different source populations: Elbe, Weser, Odra, Maas and the Humber River, where the first three may arrive at the Bay of Kinneviken and the latter at the city of Kristinehamn in the northern part of Lake Vänern (Table 3). The difference in mitten crab abundance within Lake Mälaren during 2004-2005 and 2006 in particular (Figure 2) is not easily explained by the difference in ship transfer routes, since they share similar ports of call. It is likely however that these observations are influenced by the developmental stage within the European mitten crab population and time of year of the invasion. Mass migration of adults, zoea development, or megalopa settlements do not occur at the same time during the year. Further research and joint global collaboration are needed to fully understand the distribution patterns of the Chinese mitten crab. The possibility of several invasion routes of mitten crab into Sweden and the lack of a global/European coordinated information structure of the breeding successes and species abundance highlight the need for an early warning system. This is especially important, because human mediated transport constitutes an important role in the spread of the Chinese mitten crab (Herborg et al. 2007b).

Published "semi-quantitative" information of the crab population densities in the German rivers Weser, Elbe and Havel indicates a cyclic abundance with peaks at about every 12 years (Fladung 2000) or 15 years (Hymanson et al. 1999). The last abundance peak in the Elbe River occurred in 1997-1999, which would suggest that a new increase is likely to occur in the near future (Fladung 2000). Mitten crab density in the Elbe River has declined during the past ten years, as indicated by the number of upstream migrating juveniles during springtime (Gollasch and Fladung pers. comm.). A more recent decline was also observed in the Oder River (Czerniejewski pers. comm.).

Catch reports of the Chinese mitten crab from professional fisherman are hard to retrieve on a voluntarily basis in Sweden. This may depend on several factors indicating the lack of will or knowledge where to report the observation or a general lack of interest from decision-makers or the Fisheries department. Observations from the general public around the coastal areas in Sweden, not including professional fisherman from Lake Vänern and Lake Mälaren, were shown to reflect the temporal and spatial distribution of the mitten crab in Lake Mälaren and Lake Vänern. The lower number of observations from the western coastal region of Sweden in relation to the eastern coast (Figure 1) could depend on two things. First, there is no formal legislation in Sweden that forces a citizen to report the finding of alien species. Secondly, general knowledge as to whether a species is an alien or domestic is low in regions where crabs of other species [*i.e. Carcinus maenas* (Linnaeus, 1758), *Liocarcinus depurator* (Linnaeus, 1758) and *Cancer pagurus* Linnaeus, 1758] are particularly abundant. So far, different species of

crabs are only found along the Swedish west coast were the water salinity is higher than on the east coast. Consequently people on the east coast will be more prone to report their findings.

A potential reproductive area in Sweden?

The sexual bias observed within the small sample of mitten crab from Lake Vänern (Table 2) may indicate a pattern of adult downstream migration (Rudnick et al. 2000), which starts with small males followed by small females. Subsequently the larger males migrate and finally the larger females. Panning (1939) and Czerniejewski and Wawrzyniak (2006) argued that the females start their migration first. The higher abundance of larger males in Lake Vänern could then be a consequence of an early female migration.

From observations on gonad development of several crab specimens of both sexes collected in Lake Mälaren and Lake Vänern in 2007, it appeared that ovigerous females are very rare and were reported twice only in Sweden, i.e. on the coastal archipelago south of the Göta Älv River estuary during springtime 2004 (Per Herfors pers. comm.) and from Laholmsbukten in May 2008 (local fisherman report). Moreover, coastal fishermen have noticed an increased number of mitten crabs since the late 1990's in the Göta Älv River estuary. In recent years, a fisherman may collect around 30 crabs during springtime eel fishing. This observation is congruent with recent data from the Baltic region (Ojaveer et al. 2007). The observation of an ovigerous female near the Göta Älv estuary implies that reproduction might be possible within this region. Preliminary reproduction studies at the Institution of Aven Loven Center, Kristineberg (Göteborg University) support this (Matz Berggren pers. comm.). This possibility was put forward as early as 1932 by Lönnberg (1932) who emphasised that the Göta Älv and Nordre Älv River estuary near Göteborg may be a prime candidate area for a self-sustaining mitten crab population. The presence of a major estuary is always needed to have a successful establishment of the crab locally, as observed in almost all established European crab populations (Rudnick et al. 2005; Hanson and Sytsma 2007). In addition, the interactions between salinity, temperature, flushing time and estuary size must also be favourable. In particular, the retention time of the larvae within the estuary has been put forward as an important factor for the development and maintenance of a crab population (Hanson and Sytsma 2007). The Göta Älv and Nordre Älv River Estuary are part of a very extensive region on the Swedish west coast comprising of small and large connected estuaries. The total length of this region, stretching from Strömstad in the north to Varberg in the South, is approximately 220 km with an area of 2200 km^2. Within the overall region water plumes from local fresh water rivers intermix with regions having no large estuaries. Extensive areas of small islands between the coastal areas and the open ocean could create ample habitats and favour longer flushing times. A consequence of this is that some areas within this entire region may have lower flushing times than the region where Göta Älv and Nordre Älv Rivers empty into. Moreover, the salinity in this region lies normally between 20 to 25 psu but can occasionally increase to 30 psu.

The development time from a zoea I larva to the megalopa stage at salinities of 20 to 25 psu and with a mean water temperature of 12ºC is approximately 90 to 110 days (Anger 1991). Under these conditions, the survival of zoea larva would be relatively good (approximately 60%); but only 5% would however survive the transition to the megalopa stage. At 15ºC, the survival would increase to 45%. The mean temperature in Göta Älv River estuary is very similar to the annual temperature regime in Hamburg (Germany). In late April the mean surface water temperature is around 8-10ºC and gradually increases to a value of 11-12ºC in May and 14-16ºC in June (SMHI 2007). The larvae hatch in late March in Germany at 4-8ºC, a temperature very similar to that observed in the Göta Älv River Estuary. The water salinity (low salinity due to snow melt and rain in early spring) in relation to temperature may, however, be a confounding factor for mitten crab reproduction in Sweden and survival of the Megalopa stage (Rudnick et al. 2005). In Sweden different climatic models, presented by the IPCC (Intergovernmental Panel on Climate Change), predict an increase in mean temperature of 4-6ºC in the coastal region of Göteborg (SMHI 2010) until the year 2100. Such an increase could make the crab less sensitive to the lower salinity (Anger 1991). Under such a scenario, the possibility that we will observe a self-reproducing Chinese mitten crab population in the Göta Älv River estuary in the future is indeed considered high.

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Supplementary material

The following supplementary material is available for this article.

Appendix 1. The reports of the Chinese mitten crab (*Eriocheir sinensis*) in Sweden since 2007. Coordinates are given from the international WGS84 system (longitude and latitude) along with reporting year, geographical region and municipality. If coordinates were missing in the original report they were established as close as possible to the written description of the observed location. Note that one coordinate set may represent more than one specimen. All records are searchable in the Chinese mitten crab public registration portal at the Swedish National History Museum (http://www.nrm.se/ullhandskrabba) and will be available at GBIF Sweden (http://www.gbif.se) and Regional Euro-Asian Biological Invasions Centre information system (http://www.reabic.net).

This material is available as part of online article from:
http://www.aquaticinvasions.net/2010/AI_2010_5_4_Drotz_etal_Supplement.pdf