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Research Article

Distribution patterns of the Chinese mitten crab (*Eriocheir sinensis* H. Milne Edwards, 1853) in Lake Vänern, Sweden

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Abstract

The catadromous Chinese mitten crab (CMC), *Eriocheir sinensis* is well known for its extensive invasion routes across the world. However, little is known about both adult and juvenile behaviour after they arrive to a new region. Particularly if the CMC has utilised freight ship ballast tanks as its invasion vector to new freshwater areas like coastal connected larger lakes. The Swedish Lake Vänern, Europe's third largest freshwater lake, offers a suitable study area since only a handful of CMC had been reported between its first record in 1954 and 2004. Hence, the increased catch of of CMC in the mid 2000s was unexpected and provided a rare opportunity to study the initial phase of a biological invasion. Fortunately local fishermen have traditionally, since the mid 1970s, utilised large stationary fish trap nets, evenly distributed from the inlet to the harbour of Lidköping outward into the main part of the lake. During the peak occurrence in 2005 the traps captured CMC frequently for 90 days starting on August 10. Daily catch increased from September 19th to October 17th. Thereafter the number decreased until November 7th when the last crab was captured. Only one crab out of the 21 caught in the two traps furthest away from the harbour inlet was caught before September 19th. The number of caught CMC differed significantly between the trap nets. Almost half (48.4 %) of all CMC were caught in the two traps closest to the harbour inlet and 41.9% in the second trap-line, consisting of two traps 6 km from the harbour inlet. The remaining crabs were caught in the traps furthest away. Catch pattern from this unique invasion event is discussed in relation to CMC dispersal/migration, invading sample size, behavioural traits and catch efficiency of traps.

Key words: freshwater, initial invasion, behavior, catch pattern

Introduction

The catadromous Chinese mitten crab (CMC), *Eriocheir sinensis*, H. Milne Edwards, 1853 (Crustacea: Brachyura: Varunidae) is well known for its extensive invasion routes across the world (Panning and Peters 1932; Peters 1938; Lönnberg 1932; Hymanson et al. 1999; Veldhuizen et al. 1999). It has been documented that human mediated transport constitutes an important role in the spread of the CMC (Herborg et al. 2007a, b, c). The secretariat of the Pacific regional environment program (SPREP 2010) has estimated that more than 5,000 species of aquatic organisms might be transported around the world each day of the year in ballast water. It is likely that the CMC larval and juvenile stages were initially unintentionally transported in ballast water from native estuaries and coastal rivers in China and Korea. Later areas of established CMC populations serve as new sources for extended invasions in Europe. The newly settled juvenile crabs live within the estuaries for months prior to their upstream migration to brackish or freshwater. Juveniles have been documented to perform migrations spanning from some hundred meters up to an amazing 15 km per day in the Havel river system in Germany (Panning 1938). Correspondingly adult specimens, who can live for years maturing in freshwater, have been documented with similar downstream migration rates in late autumn (Panning 1938).

Upon a successful invasion and breeding event the juvenile is assumed to be the key stage for secondary spread into new areas (Gilbert et al. 2008). However, little is known about how adult and juvenile crabs behave after arriving to, or becoming established in, new areas. Particularly if the CMC has utilised ballast water tanks as an

Figure 1. Map showing Sweden and Lake Vänern, inset of the Bay of Kinneviken in Lake Vänern and the trap nets position (●) and trap-lines. The position of trap-line 1 (Lockörn – Kartåsen, marked with —); trap-line 2 (Sjölunda – Filsbäck, - - -) and trap-line 3 (Fästa – Källby, - - -). The inlet to the harbour of the City of Lidköping lies near the outlet of the Lidan River.

invasion vector to a new catchment i.e. coastal connected freshwater lakes. The few studies that have been undertaken with regard to dispersal or migration of the CMC are within estuaries (Panning 1938; Jin et al. 2001; Rudnick et al. 2003; Rudnick et al. 2005).

The aim of the present study was to observe the initial invasion of adult CMC within a freshwater lake, which is a clearly important but scarcely studied occurrence (Strayer et al. 2006). Lake Vänern, connected to the North Sea via the Skagerrak coastal region is the third largest freshwater lake in Europe with an area of 5650 km^2 (Figure 1). The size of ships, measured in how much weight it can safely carry, that enter the lake varies between 1300 and 7000 tons (deadweight tonnage) and are between 82 to 107 meters in length and between 12 and 17 meters in width. Shipping goods are dominated by artificial fertilizer and forestry produce; however, petroleum products, coal and iron are also common. So far there has been no indication of an upstream migration of crabs from the Skagerrak region via Göta River to Lake Vänern. The only outlet from Lake Vänern to Skagerrak is via the Göta River. The distance between the North Sea and Lake Vänern is 150 km and the distance between Vänersborg and Lidköping is around 80 km across Lake Vänern. Such distances are well within the crabs' normal migration range (Panning 1938). This implies that the study area is suitable for studies of an initial invasion of CMC, and also because prior to 2004 only a few CMC had been reported by the local fishermen (Lundin et al. 2007). During the years thereafter the abundance of crabs has decreased in Lake Vänern (Drotz et al. 2010a, b).

Materials and methods

The migration of mitten crabs within Lake Vänern was studied using six large stationary fish trap nets, with pot sizes of 10 to 15 m^3 connected to leader arms of several hundred meters in length, near the inlet to the harbour of Lidköping (Figure 1). The substrate in the inner parts of the Bay of Kinneviken, where the trap nets are situated, consisted of a fine layer of sand with minor areas with exposed clay. The bottom and brinks closest to the harbour outlet were covered by deposit material (larger and smaller rocks from a few meters to some centimetres). To catch the CMC, six traps (3 on each side of the harbour inlet) were used pair-wise and separated by a distance of 3 km. The two closest equally distant trap nets near the shore line on either side to the harbour inlet were called trap-line 1. Each trap-line represented a distance from the harbour inlet. The trap-line second closest to the harbour inlet was called trap-line 2 and finally trap-line 3 was furthest away from the harbour inlet (Figure 1). Trap nets have been used within this area for more than six decades and are placed in the water after the ice melts in late March or early April and stay in the water until late October or early November. Fishing effort within this region has been more or less constant during the same time period. The fishing effort during this study was the same regarding position and time interval of empting/checking the nets. Crabs caught between 2004 and 2006 were killed by the fishermen on the boats as a pest or vermin in the gear and therefore were neither sexed nor measured. The fishermen were not paid for catching mitten crabs and subsequently there was no economic gain for the fishermen. After an agreement with some of the fishermen the crabs caught between 2007 and 2010 were kept alive and transported to the Lake Vänern museum of natural and cultural history where they could be sexed and measured.

Statistical analyses

The spatial and temporal variation of the caught CMC was only analyzed in 2005 due to the lower numbers of reported crabs in 2004 and 2006 to 2010 (Drotz et al. 2010a). In 2005 crabs were captured for 90 days between August 10th and November 7th. Reported trap-line catches were calculated as the sum of captured crabs within the trap pairs equally distant from the harbour inlet (Figure 1). Observed catch differences by trap-lines were tested to a prior distribution assuming an equal catch for every trap-line. The test was carried out using Chi-square analysis. To test the temporal relationship between the capture dates of CMC within separate trap nets position, these were tested using ANOVA analysis. Capture dates were converted to Julian Day as described by Seidelmann (1992).

Results

During the initial invasion of Chinese mitten crabs in Lake Vänern in 2004 to 2006 local fishermen collected a total of 303 crabs in trap nets distributed near the inlet to the harbour of Lidköping (Figure 2). In 2005 the fisherman caught 217 crabs between August 10th and November 7th, with the largest catches between September 19th and October 17th (Figure 3). During this time period crabs were caught continuously in the four traps closest to the harbour inlet. Only one CMC out of the 21 caught in trap-line 3 was caught before September 19th. However, there was no significant difference detected between trap net position and the mean day-number of caught CMC (*ANOVA*: P-value 0.584).

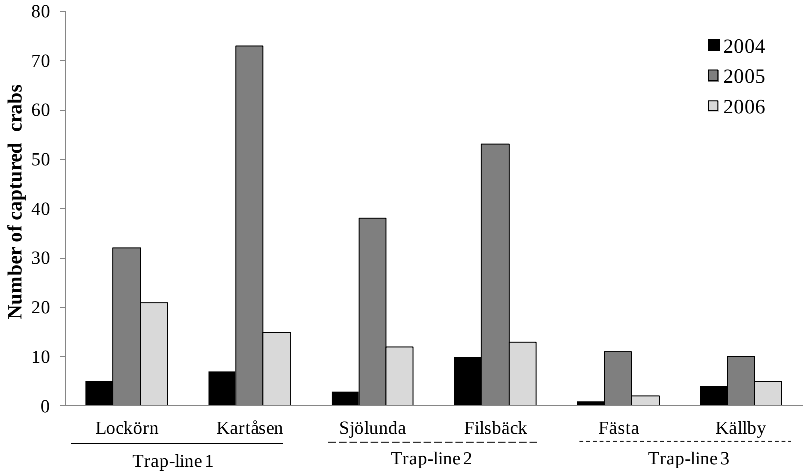

Figure 2. Yearly catch of the Chinese mitten crab, *Eriocheir sinensis*, based on the trap net fishing in Bay of Kinneviken, Lake Vänern, during 2004-2006. Trap nets positions and trap lines grouping and the harbour inlet is shown in Figure 1.

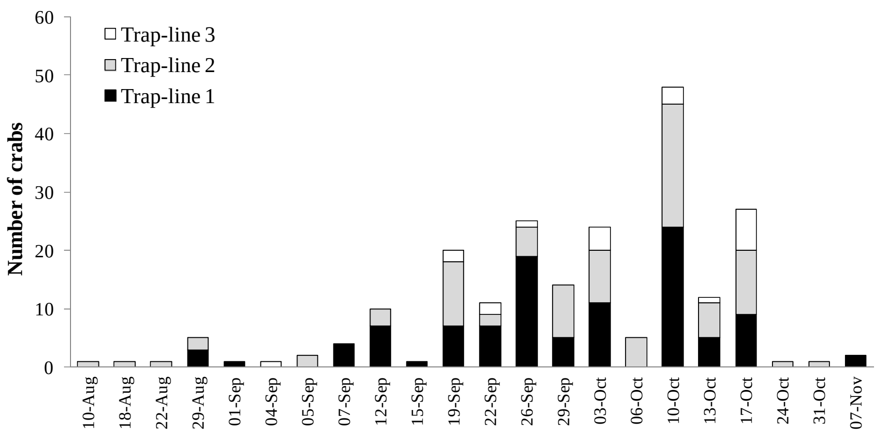

Figure 3. Total catch of Chinese mitten crab, *Eriocheir sinensis*, in the Bay of Kinneviken, Lake Vänern, during 10 August to 7 November in 2005. Each column shows the combined catch from six trap nets along the shore line on either side of the harbor inlet in Lidköping (see Figure1). The two nearest trap nets of the inlet is here called trap-line 1, the next two trap nets are called trap-line 2 and the final two nets trap-line 3.

In 2005 the distribution of caught CMC between the trap-lines differed from an equal distribution with less crabs caught in trap-line 3 (C*hi-sq*: P-value << 0.001, Figure 2). Almost half (48.4%) of all CMC were caught in the trap-line 1 closest to the harbour and almost as many (41.9%) in trap-line 2. The remaining CMC (9.7 %) were caught in the two trap nets furthest away from the inlet, trap-line 3. A similar pattern was found in 2004 and 2006, but could not be statistically analysed due to low number of reported crabs (27 and 59, respectively) (Figure 2).

Discussion

When it comes to invasive brachyuran crabs there are some species that stand out, for example in seawater the two *Hemigrapsus* species (*H. takanoi* Asakura and Watanabe 2005 and *H. sanguineus* (de Haan, 1835)), where both species have established themselves in coastal waters on both side of the northern Atlantic and are found to successfully compete with the natural fauna. The European shore crab, *Carcinus maenas* (Linnaeus, 1758) is another invasive crab in coastal waters outside Europe

(Holmes 2001). In brackish water, the small crab *Rhithropanopeus harrisii* (Gould, 1841) is spreading in estuaries in Europe and also in lakes in some states in U.S.A. But so far the most successful invader is the Chinese Mitten Crab, which has successfully established itself in many coastal areas in the world and migrated up rivers. A comprehensive review of CMC is given by Dittel and Epifanio (2009). When established they can become a major pest and it can happened very quickly like in the Sacramento Delta where the number of captured crabs, on fish screens in front of the water pumps, went from 45 specimens during 1996 to 25000 specimens on one day alone in September two years later (Stienstra 1998). This example clearly shows the importance of learning more about how adult and juvenile crabs behave after arriving to, or becoming established in, new areas.

Our data suggests that the CMC might stay in close vicinity to the arrival zone, a pattern that is both seen within the disjunct distribution of CMC during several years in Lake Mälaren (Drotz et al. 2010a) and between different trap nets in Bay of Kinneviken, Lake Vänern (Figure 3).

There are at least three different possible explanations for the pattern of catch presented here. First, and maybe most probable, the CMC might be more or less stationary at the point of release (especially if they occur in a low abundance) and only a small portion of the population disperse far. It has been shown that the fraction of a population that disperse far might be of a very specific phenotype, either morphologically, behaviorally or both. For example, a recent study of mosquitofish, *Gambusia affinis* (Baird and Girard, 1853), showed that individuals dispersing far were both bolder and more asocial than resident individuals (Cote et al. 2010a). Secondly, we would expect to find a similar catch pattern if all or at least most of the CMC are actively moving outwards, from the point of release, along the shoreline of the lake. This would mean that the closest traps would catch higher numbers of CMC simply because more CMC encounter them. The subsequent traps will catch less and less because of the trap-induced thinning of the dispersing population. Thirdly, the pattern could be an effect of behaviour-selective catch (Biro and Dingemanse 2009). CMC with a certain behaviour (e.g. that are bolder and more exploratory) might, to a higher degree, be caught in the closer traps while the rest of the dispersing population of CMC to a higher degree avoids traps (Cote et al. 2010a). If this is true it means that, until we know the behavioural distribution of the invading CMC population, we cannot be certain that our data of trap-caught CMC is correlated to the density of CMC that actually moved pass any trap.

Although using mark and recapture is a suitable method for analysing migration pattern of crabs there is downside to using this technique. If this method is to be successful a fairly large number of specimens need to be marked (Thompson et al. 1998) and captured repeatedly (Otis et al. 1978) with a large average capture probability (Pollock et al. 1990; Lettink and Armstrong 2003; Wintle et al. 2004). However this is not possible when the newly invaded area only comprises a small number of crabs. Consequently, for the present study the movement pattern was quantified using a number of trap nets across the likely invasive point in the Bay of Kinneviken, Lake Vänern. The exact point of invasion is not known and could be the central harbour or further out in Kinneviken, where ships start to release their ballast water before they reach the harbour.

In addition, without the distribution of behaviour in the CMC population it is very difficult to know whether the pattern would have been produced by the second or third explanation, or by a combination of both. A possible contributing factor for this behavior is the occurrence of the signal crayfish, *Pacifastacus leniusculus* (Dana, 1852), in the harbor area. CMC is known to be more likely to stay hidden when in the presence of *P. leniusculus* (Rudnick 2000). However, the outward dispersal of CMC showed here is fast (Figure 3) and it gives an indication that the spread of this species could be a very fast process. The CMC may therefore go from being a rarity to pest status very fast; with potentially immense ecological effects as a result (Bendfeldt 2009). More studies on both personality-driven invasions and of what determines the fitness of an invader are certainly needed to increase our understanding of the invasion process and subsequent effects on ecosystems like Lake Vänern (Cote et al. 2010b).

The size of caught mitten crabs in Lake Vänern between 2007 and 2010 lies within the same size range of CMC caught in other European countries (Drotz et al. 2010a) like Poland (Czerniejewski et al. 2003; Czerniejewski and Wawrzyniak 2006), Germany (Fladung 2000; Herborg et al. 2003), Great Britain (Wall et al. 1983) and also the United States (Rudnick et al. 2000). Noticeably, no small specimens <20 mm carapace width (CW) were caught in Lake Vänern in 2004 to 2006 according to the local fishermen (pers. comm. Christer Ström). However, a handful of smaller specimens (CW of around 40 mm) has been found in Göta River and in Bay of Kinneviken, Lake Vänern through the years (Lundin et al. 2007; Drotz et al. 2010a, b). This pattern could be explained by either of two reasons. First, the invasion was started by juvenile CMC, but the fishing gear used was unable to catch any due to the small size of the juveniles. Consequently, there is a possibility that the CMC, after they were flushed out from the ballast tanks prior to the arrival to the Lidköping's harbour, walked through the trap nets (mesh size 26 mm) to reach the shoreline. This directional migration of the juvenile CMC is what could be expected if the invaders are released from the ballast water as late megalopa or in a newly metamorphosed stage of first crab (first juvenile stage) instead of migrating upriver from an estuary region. A late megalopa larva can probably survive and metamorphose in fresh water if the temperature is suitable (Anger 1991). In this case the CMC is likely to search for a habitat where it is protected from predation in the critical phases of the first numbers of moulting when the crab is still very small and where there is a high concentration of food. The harbour zone in Lake Vänern offers a very suitable habitat in contrast to the sandy bottom of the lake where the freight ships starts to discharge its ballast water prior to arriving at the harbour. The second possibility is that the invasion was carried out by pre-adults of a larger size, specimens that were discharged with ballast-water release in the harbour. Hence, the observed CMC catches from 2004 to 2006 may represent for both scenarios an outgoing migration of larger specimens along the shore line from the harbour inlet.

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