Rapid Response Plan for Management and Control of the Chinese Mitten Crab

Northeast United States and Atlantic Canada

NOAA
Sea Grant New Hampshire
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Executive Summary

The *Rapid Response Plan for Management and Control of the Chinese Mitten Crab* is intended to guide efforts to mitigate the further introduction and spread of the Chinese mitten crab in the northeastern United States and Canada. Due to the unique challenges of invasive species introductions to marine and coastal ecosystems, the mitten crab and other existing and potential marine invasive species are more difficult and often more costly to manage or control than freshwater aquatic or terrestrial invasive species. These challenges include ecosystem connectivity across vast geographic areas, ocean currents and tidal influence, and shipping- and ballast-related vectors for larvae. Warming ocean and coastal waters and species range expansions influenced by climate change will further compound these issues.

Recent and historical efforts to control or eradicate invasive mitten crab populations in other countries and in other parts of the United States have not been effective. More than a century of efforts to control or eradicate other marine invasive species, such as the European green crab, has also proven unsuccessful. For these reasons, it is prudent to focus available funds and regional capacity for early detection and rapid response planning on prevention, as we must assume that eradication is not likely should Chinese mitten crabs enter Rhode Island, Massachusetts, New Hampshire, Maine or Maritime Canada.

The Sea Grant Programs in Massachusetts, New Hampshire and Maine worked with local, state, regional and federal stakeholders to establish a foundation for prevention, early detection and rapid response efforts of the Chinese mitten crab. As part of these efforts, the staff members:

- brought partners together and identified state and provincial contacts for rapid response and identified the Northeast Aquatic Nuisance Species (NEANS) Panel as the central coordinating body and source of taxonomic expertise.

- collected historical and ecological information on mitten crabs and conducted a review of management and control efforts undertaken elsewhere.

- developed outreach resources necessary to support new and existing monitoring networks (both active and passive).

- conducted outreach activities in three states, with primary audiences including harbor masters, recreational boaters, aquaculturists, volunteer monitors, natural resource managers and shellfishermen.

- conducted habitat suitability analysis for major estuaries in Mass., N.H., and Maine, and provided a model for further habitat analysis work.

- identified and shared steps necessary for coordinated rapid response and follow-up monitoring.

For effective prevention and response planning to occur, it is essential for continued cooperation between and among local, state, and federal resource management and regulatory agencies, research institutions, coastal and marine industry, outreach and education organizations, and policy makers.

Introduction

The Chinese mitten crab *Eriocheir sinensis* (Edwards 1853) is native to eastern Asia but has successfully invaded the eastern Pacific Ocean (in San Francisco Bay, Calif.), the western Atlantic Ocean (the Hudson River Estuary, N.Y., and the Chesapeake Bay, Md.) and the eastern Atlantic Ocean (western Europe from Scandinavia to Spain). Where non-native populations are established, efforts to eradicate the mitten crab have failed (Gollasch 2011). This species continues to be responsible for extensive economic and ecological damages in Europe, such as impacting commercial fishing gear and bait and causing destabilization of stream banks through burrowing (ANSTF 2003). The threat posed by the invasion of mitten crabs is of such concern that it is listed on the International Union for Conservation of Nature List of 100 Worst Invaders (Lowe et al. 2000).

Controlling and eradicating established invasive non-native species in the Gulf of Maine (GOM) has historically been unsuccessful. For example, despite concentrated efforts to reduce or eradicate populations of the established European green crab *Carcinus maenas* in the GOM, including fencing, trapping, and drastic measures such as spreading DDT on Maine mudflats in the 1950s and 1960s, their populations remain robust (Thayer and Stahlnecker 2006). State resource agencies throughout the GOM region must use limited funding wisely, and in many cases they have ceased costly efforts to eradicate well-established non-native species, even those that cause economic damage. The return on these investments often appear to be far too small to make them worthwhile as control effots generally require great expenses over long time periods (Brandt 2004). Instead, state and regional priorities have shifted to focus on preventing new introductions and developing rapid response protocols to keep new invaders from becoming established. Both of these priority activities – prevention and rapid response – include education and outreach efforts.

This document focuses on the use of early detection and rapid response as a tool to prevent the introduction and spread of Chinese mitten crabs and other crabs belonging to the genus *Eriocheir* throughout northeastern United States and Atlantic Canada. This document will refer to all *Eriocheir* species as Chinese mitten crabs or mitten crabs. It outlines a plan of action designed to prevent unintentional transport or introductions, and to document and remove any live crabs in the GOM. The primary goal of this plan is to provide information needed to support local, state, and regional efforts to prevent and control the spread of Chinese mitten crabs throughout northeastern United States and Atlantic Canada.

Structure of the Rapid Response Plan

Prevention and monitoring are the critical first steps for combatting invasive species such as the mitten crab. Because of federal regulations, legal import of the Chinese mitten crab is prohibited and several states have added legislation to minimize invasion as well. However, organisms may invade an area despite proactive prevention efforts, and the appearance of the Chinese mitten crab on the East Coast is an example of this. To prepare for the potential expansion of the crab along the East Coast of the United States and Canada, this plan focuses on early detection and rapid response methods for addressing mitten crabs once they have been detected. The first section provides background information on mitten crabs, their native range, life history and potential impacts on ecosystems and economy. The next section presents the possible mechanisms of their introduction and discusses the importance of preventing new invasions. The following section identifies potential mitten crab habitat in the GOM based in large part on the successful invasions of mitten crabs globally. The outreach section identifies approaches to early detection through coordination of volunteers or professionals currently working in the field. The rapid response section details a step-by-step plan of response once the mitten crab has been detected, including a literature review of methods with application to specific locations. Potential resources for funding an early detection or rapid response effort are listed in the next section. The last section provides a list of outreach, policy and research needs for the effective management of mitten crabs.

Background

Identification

Chinese mitten crabs are catadromous, meaning that they reproduce in estuarine and marine waters and settle out as juveniles in freshwater streams, where they may spend months to years before migrating back into higher salinity waters to spawn. Both the adults and juveniles are easily identified in the field. As an adult, the Chinese mitten crab is a medium-to-large sized greenish or brownish crab that may be observed in freshwater, estuarine or marine habitat depending on the stage of its life cycle. Both adult and juvenile Chinese mitten crabs have a notch between their eyes, with two small spines located on either side of the notch. The carapace has four lateral spines on each side, the fourth spine being smaller than the rest. The crab's legs are approximately twice the length of the carapace width. Sex can be determined in crabs larger than a few centimeters in width by examining the morphology of the abdomen — males have a narrow abdominal flap, while females have a wide abdominal flap that extends to the abdominal edge when fully mature (Figure 1).

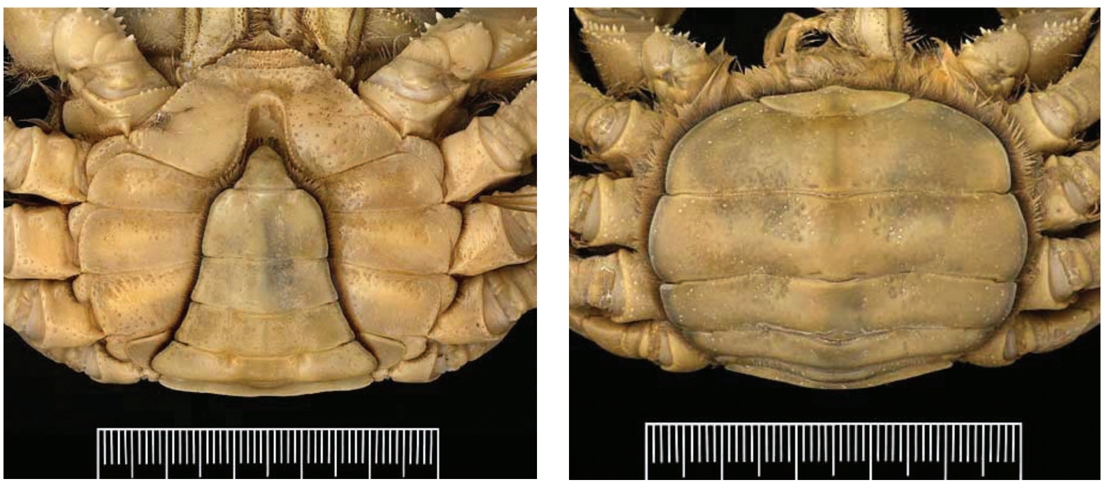

Figure 1: Detail of the abdomen of a male (left) and female (right) Chinese mitten crab. ©The Trustees of the Natural History Museum, London.

Figure 2: Adult Chinese mitten crab (Source: Smithsonian Environmental Research Center).

Figure 3: Juvenile Chinese mitten crab (Source: Sarah H. Fernald, Hudson River National Estuarine Research Reserve).

One of the most notable features of adult Chinese mitten crabs are their white-tipped claws covered with large dense patches of brown setae or bristles that look like "hairy mittens" (Figure 2). The claws tend to be equal in size, but larger on males than females, and males have fuller and wider patches of setae (Hoestlandt 1948). Adult carapaces are slightly wider than long and range from one to four inches (30-100 mm) in invasive San Francisco Bay populations (Rudnick et al. 2000; Rudnick et al. 2003; Veldhuizen 2001).

Juvenile crabs begin to develop noticeable brown setae on their claws once the carapace is greater than one inch (25 mm) in width. The setae are minimal or lacking with a carapace width under 0.8 inches (20 mm; Figure 2). Coloration is light brown-orange to green-brown, with juveniles being more brown-orange than adults and newly molted crabs (Zhao 1999). In the absence of the "hairy mittens" that juveniles may not have yet developed, juveniles are best identified by the presence of the notch between the eyes and lateral spines on the carapace. (Figure 2)

Taxonomy and Systematics of Mitten Crabs

Mitten crabs (previously placed in the family *Grapsidae* but now classified in *Varunidae*) consist of eight distinct species placed in several genera; seven of these species are recognized based on a combination of strong genetic and morphological evidence (Naser et al. 2012), while an additional species has recently been described based upon distinct morphological characters (Sakai 2013). At least three of these species have been transported out of their native western Pacific waters: *Eriocheir sinensis*, treated here; *Eriocheir japonica*, a single specimen of which was collected at the mouth of the Columbia River in Oregon in 1997 (Jensen and Armstrong 2004) but not reported elsewhere since that time, and *Eriocheir hepuensis* (the "Hepu Mitten Crab"), a tropical and sub-tropical species that appears to be established in Iraq and Kuwait (Naser et al. 2013). Given these records and the existence of additional species of mitten crabs, any new records of mitten crabs should be verified to confirm that they are *E. sinensis.*

Sakai (2013) has proposed transferring *E. sinensis* (as well as *E. hepuensis*) to a new genus, *Paraeriocheir*. At this time, we retain *Eriocheir* for consistency with older literature and because of general public and governmental familiarity with this name, but acknowledge that accepted nomenclatural convention would require changing the name of the Chinese mitten crab to *Paraeriocheir sinensis*. We would defer to the World Registry of Marine Species (http://www.marinespecies.org/) but *Eriocheir* nomenclature at that site has not been updated since 2010.

Distribution and Habitat

The native habitat of the Chinese mitten crab includes the rivers and estuaries of central Asia, ranging from the West Coast of North Korea to south of Shanghai, China (Panning 1939). It has invaded large estuaries and river systems in two continents. The first record of the Chinese mitten crab in Europe was reported in 1912 when crabs were found in the Aller River, Germany (Panning 1939). Since then, the crab has become widely established on the European continent, found throughout most of western, central, and northern Europe in varying abundances (Cabral and Costa 1999; Herborg et al. 2002; Ojaveer et al. 2007). The most likely mechanism for introduction to European countries is accidental importation through ballast water or spread to adjacent countries through connected streams or coastal waterways (Cohen and Carlton 1997).

The first reported North American invasions were individual Chinese mitten crabs taken from a water-intake pipe in the Detroit River (U.S.) in 1965, and in Lake Erie in commercial gillnets in 1973 (Nepszy and Leach 1973). In 1987, crabs were found in the Mississippi River Delta (USGS 2015), as well as in other areas of the Great Lakes besides Lake Erie between the years 1973-1994 (Veldhuizen and Stanish 1999).

On the West Coast of the U.S., shrimp trawlers first reported sightings of the Chinese mitten crab in 1992, and by 1998 the crab population increased to hundreds of thousands (Siegfried 1999). By 2000, the crabs were found up to 50 km upstream from the San Francisco Bay Delta (Rudnick et al. 2003). The rapid spread of the crab population in the Bay Delta region demonstrates the potential risk for more widespread crab establishment in the U.S. and the need for effective response plans and management tactics.

More recently, the mitten crab has been found in the Great Lakes and the St. Lawrence River. Between 2004 and 2007, nine specimens were captured in both fresh and estuarine waters of the St. Lawrence River. However, it is not yet known if mitten crabs are established in the St. Lawrence ecosystem (de Lafontaine et al. 2008). In recent years, the Chinese mitten crab has been found in the Mid-Atlantic region of the East Coast in the Chesapeake and Delaware Bays, the tidal Hudson River and its tributaries, and the tributaries of Raritan Bay (Schmidt et al. 2009). The first Chinese mitten crab in New York was caught in the Hudson River in 2007, 80.5 km (50 miles) upstream of the river's mouth (U.S. Geological Survey 2015). Several ovigerous (egg-bearing) female Chinese mitten crabs were later collected in the Hudson River in 2009 (Schmidt et al. 2009). There are two possible explanations for the presence of reproductive crabs so far upstream: the gravid female crabs may have been intentionally released, or reproduction may be occurring and the crabs are moving rapidly upriver (Sarah Fernald, N.Y. DEC personal communication). Additionally, the Connecticut Department of Energy and Environmental Protection, in conjunction with Connecticut Sea Grant, confirmed that a juvenile and an adult female Chinese mitten crab were collected in 2012 and 2014, respectively, from the Mianus River in Greenwich, Conn., in both 2012 and 2014. The presence of reproductive crabs in the Hudson River and individual crabs in Long Island Sound raise concerns that the crabs will invade areas in the GOM. The locations and dates of East Coast mitten crab sightings are detailed in Appendix I.

Vectors

Given the wide geographical separation of possible source populations (Europe and East Asia) as well as crab dependence on coastal and freshwater habitats, Chinese mitten crab introductions into North American waters occurred with human assistance (Cohen and Carlton 1997). The most probable primary vectors are ballast water and intentional illegal importations (Cohen and Carlton 1997). In addition to the probability of ballast water transport as larvae or juveniles, live Chinese mitten crabs have been sold in seafood markets in the United States, and the demand for the crabs, particularly egg-bearing females, can provide an economic incentive for individuals to establish new populations of the crab in U.S. waters (ANSTF 2003). People may have thus intentionally introduced mitten crabs into non-native waters for the purpose of consumption or aquaculture establishment

(ANSTF 2003). Mitochondrial DNA sequences of the San Francisco Bay Delta population indicate a closer genetic relationship to European than Asian populations that were sampled, suggesting that there might have been a deliberate attempt to introduce the crab from Europe (Hänfling et al. 2002). Furthermore, a number of potential secondary vectors exist, including aquaculture-related transfers, recreational or small craft traffic, and commercial shipping activities, including coastal ballast water movements (Therriault et al. 2008) that may facilitate the transfer of crabs to new locations.

The highest priority for addressing marine and other bioinvasions is prevention. International and national efforts to minimize accidental or deliberate introduction of the Chinese mitten crab, as well as other species, include regulatory changes that impact importation and release of untreated ballast water. Changes in ballast water treatment, including exchange at sea and new technologies designed to meet current standards, has likely decreased accidental release of crabs. However, documenting the success of improved ballast water management is not easy to quantify.

Recognizing the ecological and economic impact of Chinese mitten crabs, the U.S. government has taken regulatory steps to control Chinese mitten crab populations. Under the federal Lacey Act, the genus *Eriocheir* is listed as injurious, meaning the importation and interstate transport of live crabs is banned (USFWS 1989). Unfortunately, federal enforcement may not catch all illegal imports and thus several states have passed their own legislation. The states of Oregon and Washington prohibit importation and possession of *Eriocheir* (ANSTF 2003). In California, the Department of Fish and Game has banned the possession and transport of live *Eriocheir* (Section 671, Title 14). Because they are abundant and established in California, with a valid fishing license it is legal to catch Chinese mitten crabs in the state's inland waters with a hook and line and immediately kill the crab after capture (ANSTF 2003).

In New York, the Chinese mitten crab was banned in January 2003 to address the illegal importation of crabs into its jurisdiction (6NYCRR Part 44.8). In the states of Maine, New Hampshire, Massachusetts, Connecticut and Rhode Island, no clear regulations have been enacted to manage the Chinese mitten crab. However, in these states (as elsewhere) officials should be notified if a Chinese mitten crab is potentially found (see Early Detection section of this publication). It is recommended that the entire genus *Eriocheir,* rather than a specific species, be designated for restriction in state regulations (Rudnick 2003).

In Canada, aquatic invasive species regulations have been proposed under the regulatory authority of the federal Fisheries Act (R.S.C. 1985, c.F-14). The Chinese mitten crab would be listed as a species subject to control and eradication efforts only in areas where they are not indigenous and where they may cause harm if introduced or are spreading. In the province of Quebec, the mitten crab is prohibited in fresh bodies of water under the Réglement sur l'Aquaculture et la Vente des Poissons (Regulation on Aquaculture and Sale of Fish). The possession, transport, stocking, farming, aquarium trade, production, captivity, sales and purchase of live mitten crab specimens are prohibited under this regulation.

Impacts

The Chinese mitten crab has the potential to cause significant impacts on ecosystems as well as humans and man-made structures in locations where it invades. Because the Chinese mitten crab has only recently arrived on the East Coast of the U.S. and populations are not well established, its impacts are not known. However, based on observations in other regions where it has invaded and become established, we can surmise that mitten crab populations in East Coast habitats may result in economic damage, impacts to food webs, habitat structure (through bank erosion), fisheries and aquaculture, energy plants, and possibly agriculture and human health.

Ecological Impacts

Chinese mitten crabs can make up a significant portion of the biomass in an ecosystem that it has invaded (e.g., San Francisco Bay Delta, ANSTF 2003). Given that the mitten crab is an opportunistic generalist predator, its introduction could result in alteration of native populations in estuarine and riverine systems. In the San Francisco Bay Delta area during periods of high mitten crab abundance, the crabs have preyed on the eggs of fish and amphibians and occupied spawning reaches for certain fish (Johnson 2001). In addition, mitten crabs fed predominantly on surface-dwelling invertebrates in a laboratory experiment suggesting that impacts to shallow-dwelling communities might occur (Rudnick and Resh 2005).

Perhaps the greatest impact of the crabs is on estuarine and freshwater riverbanks where crabs burrow into the sediments (Figure 4). Given that riverbanks protect adjacent upland flooding by diverting and capturing water, bank erosion caused by Chinese mitten crab burrowing can have both local and widespread impacts. Bank slumping and erosion are attributed to crab burrows in levee banks, marshes and adjacent areas (Rudnick et al. 2000; Johnson 2001; ANSTF 2003; Dittel and Epifanio 2009). Renewed burrowing of the collapsed banks, along with wave action, resulted in the continual removal of marsh bank sediments (Philips 2001). Estuaries and marshes on the East Coast may experience accelerated and drastic erosion with the invasion of the Chinese mitten crab, thereby reducing habitat for a number of species as well as flood protection services.

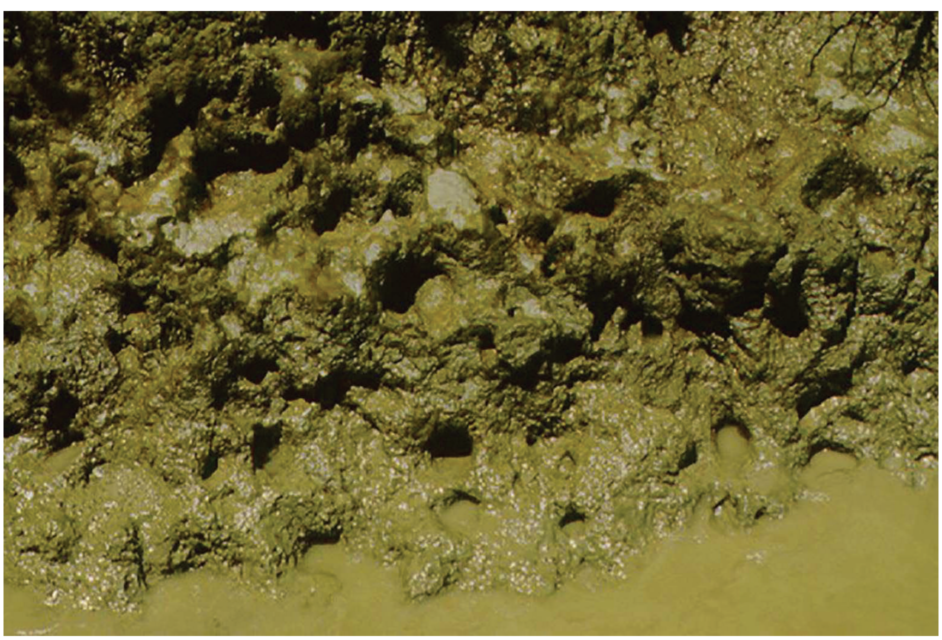

Figure 4: Example of a high density of mitten crab burrows from a stream bank in California (Source: California Department of Fish and Game). Burrows average approximately 4 cm (1.5 inches) in diameter (Rudnick et al. 2005a).

Economic Impacts

Chinese mitten crabs can interfere with both commercial and recreational fishing by damaging bait, gear, and/or the catch. In California, many areas were reported "unfishable" during periods of high crab abundance due to their severe impacts (ANSTF 2003), particularly during the fall downstream migration when crabs become concentrated in lower river systems and upper estuarine channels. Most Chinese mitten crabs are caught by fishing techniques such as slow-moving trawls that capture benthic animals from the ocean floor (Rudnick and Resh 2002). As such, the potential exists for the Chinese mitten crab to significantly affect trawl-harvested fisheries by entangling themselves in great quantities in fishermen's nets, thereby increasing handling time and damaging equipment. Additionally, the crab's spiny carapace and legs may damage the fish catch. Fortunately, trawl fisheries in northeastern U.S. and Atlantic Canada are limited to offshore waters so are likely to remain unaffected by mitten crabs. However, trap or net fisheries that do occur in East Coast bays and rivers (e.g., crab, lobster or eel fisheries) may be vulnerable to gear clogging and destruction by mitten crabs. It remains unknown whether Chinese mitten crabs feed on the same food sources as the Northeast's commercially harvested species. In addition, crabs may impact diadromous fish runs as they clog fish ladders during downstream migrations. The potential also exists for mitten crabs to impact the Northeast's finfish and shellfish aquaculture industries through predation.

Another potential impact is on nuclear and coal-burning energy plants lining the coast that use the ocean for cooling water. Chinese mitten crabs have demonstrated an ability to interfere with power plant functions in California that could easily translate to the East Coast where nuclear and coal-burning plants, extensive fish passages and water diversions exist (ANSTF 2003). For example, during the 1997 crab population increase in the San Francisco Bay Delta, natural gas power plants experienced intermittent problems with crabs clogging water intakes (ANSTF 2003). The crabs entered the cooling water intakes during their downstream migration that blocked the plumbing and drastically reduced water flow (ANSTF 2003). To remedy the problem, periodic back flushing is required to prevent the system from overheating (Hieb 1998) at additional expense to the plant.

Because much of the mitten crab life is spent in freshwater tributaries, they are known to feed on agricultural crops. In China and Korea, the crab reportedly damaged rice crops by feeding on the young shoots (Ng 1988). Although the New England region does not produce rice as a crop, cranberries are grown in floodplains adjacent to potential mitten crab habitat and may be affected by Chinese mitten crab invasion. Nonetheless, impacts to agricultural production are not thought to be a major threat in the Northeast.

The Chinese mitten crab serves as the secondary host for the Asian lung fluke *Paragonimus westermani* (Yang et al. 2000). Symptoms of the infection are typically tuberculosis-like, resulting in permanent lung damage, with mammals — including humans — as the final host (Dugan et al. 2002). Infection likely occurs through ingestion of raw or undercooked crab, or transfer of the fluke parasite via utensils that were in contact with infected crabs (Marquardt and Demaree 1985; USFWS 1989). Despite inconsistences in the literature (Wang and Hess 2002), mitten crabs in North American waters are capable of serving as the secondary host for the Asian lung fluke (ANSTF 2003). Infected crabs have not been documented in U.S. waters (ANSTF 2003), but it is prudent to assume the fluke is present in California as the vectors of introduction continue to become available (Loscutoff 2001).

Chinese mitten crabs may also bioaccumulate toxic contaminants. The California Department of Health Services found that the crabs were able to accumulate potentially toxic contaminants in their body tissue, such as arsenic, selenium, and DDE, although not to levels considered dangerous for human consumption (ANSTF 2003). Mercury bioaccumulation among mitten crab tissues varies and decreases with size, but more information is needed to determine environmental impacts (Hui et al. 2005).

Population Fluctuations

Chinese mitten crab populations often undergo large fluctuations (Gollasch 1999; Clark et al. 1998). In the San Francisco Bay Delta region, the Chinese mitten crab has established populations that flourish in a cyclical pattern and is expected to eventually populate all waterways in California connected to the Bay Delta (ANSTF 2003). In Germany, the Chinese mitten crab has undergone a "boom and bust" population cycle where it declined during the 1940s but rebounded in the '50s, '70s, and early '80s and has been increasing since the mid-'90s (Hoestlandt 1948; Clark et al. 1998; Gollasch 1999). Similarly, large decadal fluctuations in Chinese mitten crab populations have been observed in other European countries including England, the Netherlands and France (ANSTF 2003). In the Thames River Estuary, the crab population has experienced a large increase since 1992, but prior to that time the population had remained relatively constant since the '70s (Clark et al. 1998).

Although the specific factors that contribute to these fluctuations are not well understood, it is probable that seasonal and yearly variations in environmental conditions within the ecosystem play a role in determining population size. For instance, improved crab settlement coinciding with several years of drought may have influenced the recent population increase in the Thames River Estuary (Atrill and Thomas 1996). The Bay Delta population size seems to be influenced strongly by the interactions between the number of breeding female crabs, the timing of reproduction and water temperature (Blumenshine et al. 2012). However, it is not currently possible to predict crab cohort size for a future year due to a lack of long-term data (Rudnick et al. 2003). It remains unknown whether there is an established Chinese mitten crab population in the Hudson River Estuary. The population may not yet be fully established, or it may be established but be in the "bust" part of its fluctuation cycle.

Potential Chinese Mitten Crab Habitat in the Gulf of Maine

The purpose of this section is to identify suitable habitats where the Chinese mitten crab may become established in the northeastern United States. Areas are ranked with a habitat suitability of high, moderate or low. The suitability is a relative estimate based on the best available data that can and will change as more information or improved understanding of established populations provides new insights. Potential habitats are based on NOAA's National Estuarine Eutrophication Assessment Program (www.ian.umces.edu/neea/), accessed February 2015, for the Northeast that delineates estuaries from Passamaquoddy Bay, Maine (+48.02; -67.07) to the Hudson River/Raritan Bay, New York City area (+40.48; -74.18) including Long Island Sound. Criteria were established that identified the life history requirements of the species and the characteristics of estuaries that support established populations. These criteria were compared to characteristics of local estuaries to determine the potential for successful crab invasions. Although the criteria appear to be a good indicator of where mitten crabs have been found on the East Coast (e.g., Hudson River/Raritan Bay), data are lacking for some areas. Another issue not addressed is the potential for physiological adaptions to new environments that allow them to establish populations outside predicted habitats. Despite the uncertainty, the current approach provides a roadmap for monitoring estuaries deemed suitable for Chinese mitten crab invasions.

Life History Requirements for the Chinese Mitten Crab

Understanding the life history phases of the Chinese mitten crab in the context of habitat availability and suitability is a critical element in identifying the likely success of establishment. A simplified life cycle diagram (Figure 5) shows the approximate time spent in estuarine, marine, and freshwater habitats (Panning 1939; Anger 1991; Rudnick et al. 2005b; Dittel and Epifanio 2009). Established adults are found in rivers and tributaries where they may travel several hundred kilometers upstream before returning to the sea to reproduce. After mating, the females carry the eggs on pleopods under their abdomen and remain on the bottom of the ocean through the winter. The eggs need saltwater to develop into larvae and they are released in the spring in brackish water. The earliest stages appear to do best in salinities of 20-25 psu, but can develop normally in higher salinities (Anger 1991; Rudnick 2005). Both adults and juveniles are capable of going overland to bypass dams and continue upstream for one to three years before returning to the sea to mate, reproduce and die.

The larval life stages are more vulnerable. In laboratory experiments, larvae typically die at 9-10°C or less, although larvae have been found in lower temperature waters (see Rudnick et al. 2005 for summary of values). The Zoea V stage will not develop into megalopa (the last stage before metamorphosis into a juvenile crab) in salinities less than 25 psu (Anger 1991; Rudnick et al. 2005). Estuarine systems with optimal conditions for larval survival have temperatures between 12–18ºC (54–64ºF) and salinity within the requirements of the different zoeal stages (20-25 psu for early stages and 25 psu or greater for megalopa). In addition, the estuary size and flushing rate are important criteria for larval development and successful establishment of the crab.

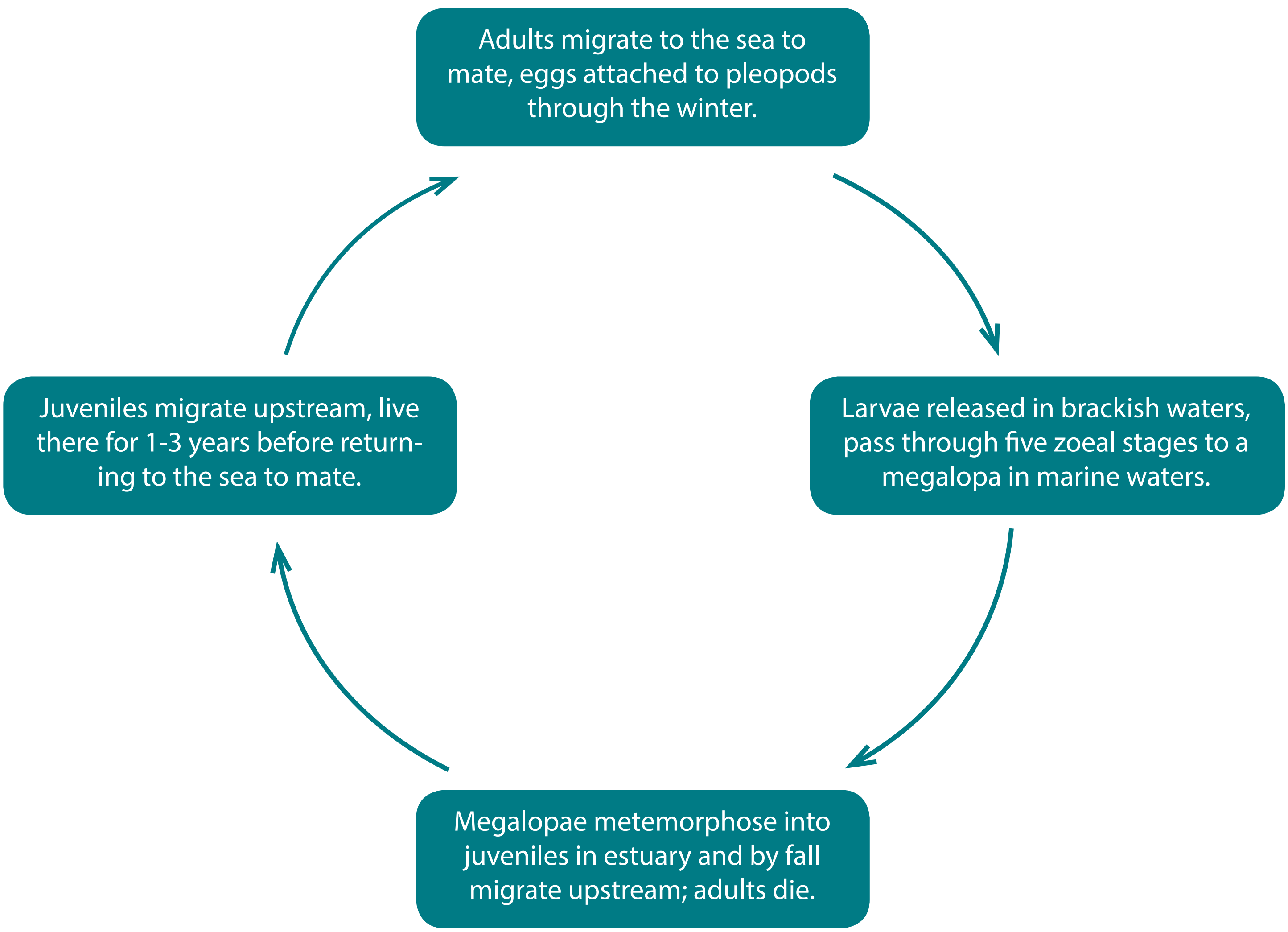

Figure 5: Generalized life history of the Chinese mitten crab. *Adults may live for one to five years; larvae may spend between 30->100 days to develop into megalopae, depending on temperature and other environmental factors. Adults die after larvae are released from eggs. Juveniles migrate upstream, grow into adults and return to the sea to mate.*

Criteria for Determining Habitat Suitability

The first set of criteria examined the latitudinal distribution of crabs and the annual temperature range of the region (Cohen and Weinstein 2001). The mitten crab is found in China and Japan with the most abundant population in the Yangtze River, China. Table 1 summarizes the latitude and annual temperature range for established populations in China, Japan, Europe, the United Kingdom and California, as well as sightings of crabs in the East Coast of North America. All areas within the East Coast fall within the latitudes where Chinese mitten crabs have established populations.

Table 1: Latitude ranges[a] of Chinese mitten crab and corresponding yearly temperature ranges for each region.

Region	Latitude[a]	Temperature Range	Comments
China	22-42°N[b]	0-27°C[b]	Most abundant population is in the Yangtze River, China; temperatures are 8-27°C[b]
Japan	30-35°N	2-21°C; 18-31°C[c]	http://www.seatemperature.org/asia/japan/ (north and south coastal temperatures)
Europe	45-54°N	6-23°C[b]	Established populations. Combined latitudes for Western Europe, Germany, and France
United Kingdom	51.5°N	5-23°C[d]	Established in Thames
California	37-40°N	8-25°C[c]	Established in San Francisco Bay Delta
Hudson	40-42°N	0-24°C[e]	Observed, gravid females found
Delaware	38-39.7°N	8-31°C[f]	Observed but not established
Chesapeake	37-39°N	0-27°C[g]	Observed but not established
St. Lawrence	46-49°N	>2-18°C[h]	Observed but not established
Maine to western Long Island Sound	40-45°N	2-22°C[i]	Areas of concern, Gulf of Maine and areas to the south

[a] http://www.latlong.net/
[b] Cohen and Weinstein 2001
[c] http://www.seatemperature.org/asia/japan/ (north and south coastal temperatures)
[d] Attrill and Thomas 1996
[e] http://www.hrecos.org
[f] http://www.njfishandwildlife.com/artdelbaystudy12.htm
[g] http://mddnr.chesapeakebay.net/bay_cond/bay_cond.cfm?param=wt&station=cb52
[h] http://slgo.ca/observations/?lg=en
[i] http://www.neracoos.org/datatools/climatologies

Temperature and Salinity Requirements

Both reproduction and the larval stages have specific requirements of temperature and salinity. Reproduction does not occur above 18-20°C (Guo pers. comm. 1996, Zhao presentation 1999 in Cohen and Weinstein 2001) and larvae have complicated temperature and salinity requirements for growth and survival. Optimal temperatures for larval growth are generally between 15-25°C. Several laboratory studies examined growth of larvae in endemic areas, Europe, and California (Panning 1939; Anger 1991; Hymanson 1999; Cohen and Weinstein 2001; Rudnick et al. 2005b). The most comprehensive study was conducted by Anger (1991) who reared larvae at three temperatures (12, 15 and 18°C) at each of five salinities (10, 15, 20, 25 and 32 psu). Two laboratory studies confirm salinities between 20-25 psu as optimal (Anger 1991; Blumenshine et al. 2012), but larvae are observed in higher salinities that are not considered optimal (Cohen and Weinstein 2001). In laboratory experiments, larvae do not survive in temperatures below 10°C and the last zoeal stage (Zoea V) does not molt to a megalopa in salinities less than 25 psu (Anger 1991). The megalopa live for 20-30 days, and during this time they migrate to brackish waters which they tolerate and metamorphose into benthic juveniles. Globally, habitats that support Chinese mitten crabs have summer surface temperatures between 18-30°C, but temperatures higher than 31°C are likely to cause mortality (Guo pers. comm. 1996 in Cohen and Weinstein 2001).

Larvae pass through various stages more quickly in higher temperatures than lower temperatures. General times for development at varying temperature estimates are based primarily on laboratory experiments. At 12°C, larvae need ~97-104 days to reach a megalopa stage but die before becoming a megalopa in the laboratory (Anger 1991). Larvae need ~62-72 days to days to reach a megalopa stage and another ~3-30 days to metamorphose into a juvenile at 15°C. At 18°C, larval stages last ~37-44 days and megalopa last ~19-20 days.

Current and Potential East Coast Habitat

The East Coast estuaries examined as potential mitten crab habitat (Figure 6) were selected from the NOAA National Estuarine Eutrophication Assessment (NEEAS 2015; http://ian.umces.edu/neea/siteinformation.php). Data for temperature and salinity do not exist for all of the NOAA embayments. Averaged daily temperature and salinity data used in this report are from the Northeast Region Ocean Observing System (NERACOOS) buoys (see references, accessed August 30, 2015). Buoys from northern Maine to Massachusetts Bay (101, F01, E01, B01, and A01) are managed by the University of Maine; the Western Long Island Sound buoy (WLIS) is managed by the University of Connecticut (Table 2). All measurements presented are sea surface (taken at one - two m) temperature and salinity and are considered representative of nearshore temperatures.

Because temperatures less than nine degrees C are lethal to larvae (Anger 1991), temperatures above 10°C are assumed to promote viable larval development, even if temperatures fell below the threshold for a day or two. Based on the GOM buoy data (Table 2), the number of days that temperatures are above 10°C, 12°C and 15°C were calculated for each estuary (Table 3). Nearly all estuaries between Maine and the Hudson River/Raritan Bay fall within the temperature and salinity requirements to support Chinese mitten crabs (Cohen and Weinstein 2001).

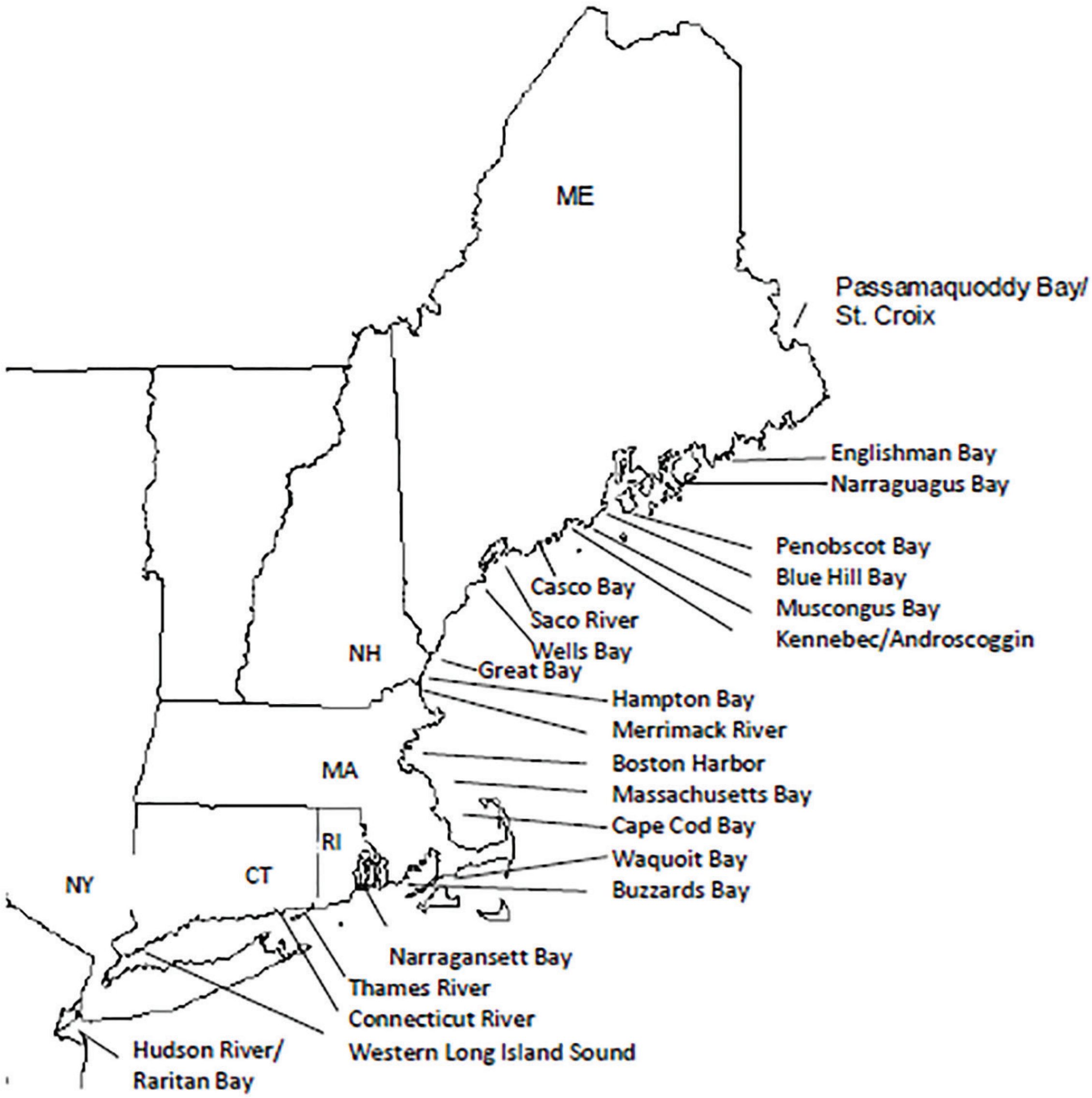

Figure 6: East Coast estuaries examined as potential Chinese mitten crab habitat.

Table 2: Names, general location, latitude and longitude of buoys used in the habitat analysis.

Location	Abbreviation	Latitude	Longitude	Water Depth
Eastern Shelf	I-01	44° 06'22"N	68° 06'34"W	100 m (328 ft)
Penobscot Bay	F-01	44° 03'19"N	68° 59'53"W	110 m (360 ft)
Central Gulf of Maine	E-01	43° 42'56"N	69° 21'18"W	100 m (328 ft)
B01 Western Gulf of Maine	B-01	43° 10'51"N	70° 25'40"W	62 m (203 ft)
AOI Massachusetts Bay	A-01	42° 31'21"N	70° 33'55"W	65 m (213 ft)
Western Long Island Sound	WLIS	40° 57'21"N	73° 34'48"W	18.3 m (60 ft)

Table 3: Water temperature and salinity for large estuaries within the region. *All data are based on mean values from August 1, 2001 to August 30, 2015 (NERACOOS).*

Location	Buoy	Total Days >10˚C	Total Days >12˚C	Total Days >15˚C	Maximum Temperature ˚C	Salinitiy Range (psu)
Near Eastport, Maine	I-01	134	62	0	12.8	30.9-32.6
Penobscot, Maine	F-01	159	120	40	16.0	21.6-32.6
Bristol, Maine	E-01	146	107	59	17.1	27.9-33.3
Portsmouth, N.H.	B-01	169	142	100	19.2	26.8-32.4
Massachusetts Bay, Mass.	A-01	183	154	109	19.2	27.5-32.5
Western Long Island Sound	WLIS	219	190	160	23.6	No data

Although the total number of days is suitable for larval development, Passamaquoddy Bay to Eastport, Maine, is unlikely to support growth because its temperature rarely goes above 13°C. Similarly, Penobscot Bay rarely goes above 18°C during the summer months, even during the warm years. Further to the south, the average number of days with water temperatures above 18°C increases from 24 days in central GOM to over 122 days in Western Long Island Sound (WLIS) during warmer years (e.g., 2012). In general, estuaries farther to the south have increasingly favorable temperatures for larval development, and therefore shorter amounts of time the larvae would spend in the water column where they are susceptible to predation.

Because nearshore water temperatures are likely to be higher than offshore waters, comparisons were made of daily averages of NOAA buoys, National Estuarine Research Reserve buoys and other buoys that provide daily temperature and/or salinity. Buoys B-01, A-01 and WLIS were similar to data from nearshore sampling stations. Buoys I-01 and E-01 were two to three degrees C cooler than nearshore areas. No daily temperature measurements were found for Penobscot Bay, but that buoy is in the mouth of the estuary. Because predicted temperature increases in nearshore waters are likely to occur with climate change (Horton et al. 2014), the potential exists for additional range expansion of potential habitats.

Salinities in offshore waters are between 25-33 psu and can support larval development. The amount of precipitation and the watershed size are important in the delivery of the freshwater into coastal systems. Salinities may go as low as 25 psu for several days in Massachusetts Bay and the Western GOM during the spring (Table 2). In Penobscot Bay, salinities may occur as low as 17.5 psu, but the salinity is often in the low 20s psu for a few days to a week in the summer (June and July) as well as in April–May and October–December. If megalopae are present at these times, the lower salinities may inhibit their survival given the higher salinity requirements at this stage. Climate change has resulted in increased average precipitation in the Northeast during the past several decades

(Horton et al. 2014) and may enhance northern estuaries' suitability and increase their risk to invasion by mitten crabs. The system from Maine to Long Island Sound generally experiences more freshwater input from melting snow and rain during the late winter and early spring months of February–May and sometimes into June. Hurricane season often brings precipitation in the fall.

Large-Scale Criteria

Ecological niche matching is a tool for predicting distributions and range expansions of invasive species based on the environmental variables of where the species is known to occur (Kolar and Lodge 2001). Data on the watershed and estuarine size, river length, flushing rate and other characteristics for areas where Chinese mitten crabs are established were used to develop large scale criteria (Weinstein and Cohen 2001; Hanson and Sytsma 2008). Five criteria based on global establishment of crabs were used to evaluate large estuaries in the Northeast are listed below. The range of values for each criterion are based on data from Table 2 (p. 607) in Hanson and Sytsma 2008.

1. Watershed area: The land-based area encompassing freshwater that empties into an estuary and indicates the area that could be impacted by maturing juvenile crabs.

2. Estuary area: The estuarine area is the area of water where the ocean meets and mouth of a river and is where larvae develop and juvenile crabs may spend a year.

3. Tidal influence: The farthest upstream extent of tidal influence, a point often referred to as the "head of tide," is another indicator of estuarine habitat. In New England, head of tide and salt intrusion are often limited by the first dam.

4. Salinity intrusion: Salt intrusion refers to the area of mixing of salt and fresh water in the estuary and is the area where larval crabs are likely to be released, grow and metamorphose.

5. Flushing time: Flushing time refers to the time it takes to replace the freshwater volume at the rate of flow through the estuary. The rate of flow varies from season to season, but the values given are averaged. The flushing time is an important factor in crab retention.

Other areas were added based on available data. For Maine rivers, the head of tide site provided valuable information (http://www.maine.gov/dep/gis/datamaps/index.html). For New Hampshire estuaries, Eberhardt and Burdick (2009) and Trowbridge (2007) provided additional information. Hudson River data were supplemented using the following web site: http://www.hudsonwatershed.org

Assessing East Coast Estuaries for Habitat Suitability

In preparing the suitability matrix (Table 4), low temperatures led to a high unsuitability ranking. Because all estuaries south of St. Croix have temperatures and salinities that support larval growth, the criteria that influence habitat suitability are flushing rates (i.e., the number of days for freshwater turnover) and size of the estuary. The values for watershed size, estuary size, flushing rate and salinity intrusion used to determine suitability were from Hanson and Systma (2008). These boundaries are guidelines for where Chinese mitten crab populations are established throughout the world. However, as mitten crabs are tolerant to a wide range of environmental conditions, it is possible they could adapt to survive in estuarine systems with average values outside these boundaries.

Another characteristic that we did not include is the location of the first dams. The data on dams in Massachusetts and other New England states are incomplete and rarely give the distance from the estuary to the first dam. These data would be useful in further refining the potential habitats for Chinese mitten crab.

Global watershed size: Between 13,000 km^2-1,808,000 km^2 or larger

Watersheds that fit within this size range are Penobscot Bay (24,500 km^2), Kennebec/Androscoggin (24,600 km^2), Merrimack River (13,000 km^2), Long Island Sound (12,780-44,560 km^2), and Narragansett (41,600 km^2); these locations are considered suitable habitat based on watershed size. Because the Connecticut River is within the Long Island Sound Watershed, it is marked a likely habitat.

Global estuary size: Between 215 km^2-1,328 km^2 or larger

Nearly half of the estuaries fall within this size range. The estuaries are Passamaquoddy Bay (406 km^2), Englishman Bay (225 km^2), Narraguagus Bay (206 km^2), Penobscot Bay (934 km^2), Casco Bay (427 km^2), Massachusetts Bay (768 km^2), Cape Cod Bay (1,439 km^2), Buzzards Bay (639 km^2), Narragansett Bay (381 km^2), Long Island Sound (3,259 km^2) and the Hudson River (799 km^2).

Saltwater intrusion is comparable to head of tide: Between 100 km-326 km upstream or farther

The length of salt intrusion is limited because most of the rivers in New England were dammed for industrial uses. The dams vary greatly in size and height, ranging from weirs across small streams that are a few feet high to dams with locks that are 15 feet or more in height. The only estuary that meets this criterion where the head of tide is greater than 100 km is the Hudson River (411 km). The distance of saltwater intrusion in remaining estuaries ranges from 0.2 km to 57 km in Penobscot Bay. It is unclear if the dams would pose a barrier to the juveniles, as they have been observed to migrate around low and sloped dams. Long Island Sound has also been identified as a highly suitable habitat because molts of a female adult and juvenile mitten crab have been found in the Mianus River (near Stamford, Conn.).

Flushing rate: Between 23-68 days or longer

Flushing rate refers to the time it takes for a given parcel of fresh water to travel through and exit from an estuarine system. The flushing rate varies with the season and has a shorter duration during wet seasons. The values from the literature do not indicate the variability and are assumed to be a mean. Estuaries that meet this criterion are Blue Hill Bay (28 days), Massachusetts Bay (60 days), Cape Cod Bay (34 days), Buzzards Bay (42 days), Narragansett Bay (46 days), Long Island Sound (56 days) and the Hudson River (126 days).

Temperature for larval growth zoeal and megalopa stages to metamorphosis (60 days at 18°C, 90 days at 15°C and 140 days at 12°C

All locations but Passamaquoddy Bay fit this criterion. Six locations with buoys that collected data daily over the course of several years were used for the comparison. The NERACOOS buoys are "offshore" and represent temperatures of coastal waters, but not necessarily of shallow embayments. The buoys have the advantage of collecting temperatures as frequently as every 15 minutes and generally are operating throughout the year. The daily summaries of temperature and salinity were used for the suitability ranking. Warmer temperatures increase larval development rates and therefore increase the suitability ranking of northern embayments where they occur.

Salinity optimum for larvae 20-25 psu

Estuaries that do not report salinities as low as 25 psu are Passamaquoddy Bay (and the St. Croix River) and central GOM. There are several estuaries where data are lacking and extrapolating from the closest buoy may not be appropriate. All of the buoys except for Penobscot Bay are offshore and may not reflect salinity changes within the estuary.

The purpose of this section is to estimate suitable habitats using temperature and salinity data (Table 3) and large scale criteria (Table 4) to assist with early detection. Estuaries that are most likely to support the Chinese mitten crab, based on environmental and habitat criteria of established populations, are the Hudson River/Raritan Bay, Long Island Sound, and possibly Penobscot Bay, although Penobscot Bay salinity may not be favorable to optimal growth. Two carapaces (a juvenile and an adult female) have been found in the Mianus River, which empties into Long Island Sound, suggesting that this is an area where established populations are likely to expand and thrive. The southern estuaries, including Massachusetts, Cape Cod, Buzzards and Narragansett Bays, along with the Merrimack River and Gardiner Bay, are also good candidates for mitten crab invasions. The lack of data or uncertainty about application of the buoy data are limiting factors in assessing suitability. As additional data are collected, these assessments can be further refined.

Several factors should be considered in the future. For the Northeast, increased precipitation due to climate change may alter salinity and hence influence the suitability for the crabs, especially in areas where salinity is currently too high for crab development. Increased precipitation also has the potential to wash larvae out of the estuarine habitats (Hanson and Systma 2008).

Similarly, increasing ocean temperatures may enhance the suitability of northern estuaries and increase their risk. This section also does not examine circulation and currents as a factor in crab distribution. In the GOM, coastal currents move from north to south and might be an inhibition to crabs moving north. However, the Asian shore crab *Hemigrapsus sanguineus* has spread northward from Cape May, N.J./Delaware Bay to southern Maine. It is possible for established southern populations to spread northward and eastward and sustain a population as occurs in the Baltic Sea (Ojaveer et al. 2007). Finally, although some areas may not be suitable (e.g., Gardiner Bay and the Thames River) that are found within a larger estuarine system (in this case Long Island Sound), the crabs may spread from an established source.

Table 4: Habitat suitability for Gulf of Maine waterbodies. *Yellow indicates that a given criterion is not suitable for growth within the estuary, orange indicates a possibility of the criterion supporting growth, and red indicates that the criterion is met. The overall rankings are classified as High (red), Moderate (orange), and Low (yellow) suitability habitats based on four or more currently available criteria. The overall ranking is classified as Unknown for sites that lack data in three or more criteria. *Indicates estuaries that would be considered low risk due to their small size, but have been ranked as high risk due to their location in Long Island Sound and in close proximity to established populations.*

Estuary	Watershed Range	Estuary Size	Salt water Intrusion	FW Flushing Rate	Temp. Days for Larvae	Salinity for Larvae Suitability	Overall Ranking of Suitability
Passamaquoddy Bay (incl. St. Croix)				No data			Low
U.S. St. Croix/Cobscook Bay							Low
Englishman Bay			No data	No data		No data	Unknown
Narraguagus Bay						No data	Unknown
Blue Hill Bay			No data	No data		No data	Unknown
Penobscot Bay							High
Muscongus Bay						No data	Moderate
Damariscotta River			No data	No data		No data	Unknown
Sheepscot Bay						No data	Low
Kennebec/Androscoggin River			No data	No data		No data	Unknown
Casco Bay							Moderate
Saco Bay							Low
Wells Bay			No data	No data			Low
Great Bay							Low
Hampton-Seabrook Estuary							Low
Merrimack River							Moderate
Plum Island Sound			No data	No data			Moderate
Boston Bay							Low
Massachusetts Bay							Moderate
Waquoit Bay			No data				Low
Cape Cod Bay			No data				Moderate
Buzzards Bay			No data				Moderate
Narragansett Bay			No data				Moderate
Gardiners Bay*			No data			No data	Low
Connecticut River							Moderate
Thames River*							Low
Long Island Sound							High
Hudson River/Raritan Bay							Present

Coordination of Early Detection, Outreach and Rapid Response

This section identifies the process for coordination of outreach, early detection and rapid response actions needed to prevent, manage and control Chinese mitten crab invasions. Invasive species are not hampered by jurisdictional boundaries. A successful prevention, detection and response program depends on coordination and effective communication among local, state, regional and federal agencies. The level of coordination required for species like the mitten crab that can migrate between marine, estuarine and freshwater aquatic systems is higher than that required for sessile organisms with known vectors. The functions associated with these activities include regulatory oversight and enforcement, research, environmental monitoring, data management, staffing and resources for rapid response and control of invasions once they occur. Local, state, regional and federal entities often work with non-government organizations, research institutions, citizen monitoring groups, industry stakeholders and other private organizations to accomplish these tasks. However, agencies collaborate and differentiate these functions in different ways according to their organizational structure, budget, and relationships with other types of institutions and industry or citizen science capacity in any given location. For this reason, developing early detection and rapid response plans for new and emerging invasive species threats is critical for effective and timely delegation of tasks and ongoing communication.

Prior to any monitoring or rapid response efforts, contacts and a mechanism for communication among the parties must be established. Ideally, this should be a federal or state entity, but often regional organizations such as the Northeast Aquatic Nuisance Species (NEANS) Panel have the interest and capability to support coordination efforts through their membership of representatives of state, provincial and federal agencies, and academic and non-government organizations. In addition, NEANS supports and coordinates outreach efforts through a regional website, small grants program and sharing of information. Because of its commitment to early detection and rapid response, the NEANS Panel will play a vital role in the initial phases of the effort by providing a list of contacts on its website and promoting communication among its members to collaborate and share information. In addition to a regional collection of data, all findings will be sent to the Smithsonian and the USGS invasive species databases that serve as national clearinghouses. Commitments by state, provincial and federal agencies are not formalized for a regional approach to addressing a Chinese mitten crab infestation. Nonetheless, many agencies and organizations have resources that are used for early detection and rapid response to address new infestations of invasive species, and they coordinate efforts locally, or on a larger scale, as issues arise. Coordination efforts need to be strengthened as the threat of Chinese mitten crab invasion increases (e.g., the expansion of crabs from the Hudson River into Long Island Sound).

Early Detection

Two general types of monitoring protocols may be followed for early detection of the Chinese mitten crab: passive and active monitoring. Passive monitoring involves searching for the mitten crab while undertaking other activities in potential mitten crab habitat (e.g., fishing, boating, recreating, diving and shellfishing). Active monitoring involves groups that are conducting search efforts focused on detecting invasive species such as the mitten crab. Of critical importance in any type of monitoring protocol is the adequate training and evaluation of all project staff and volunteers.

Monitoring for the mitten crab or any highly mobile organisms is challenging. The following monitoring recommendations for Chinese mitten crab passive and active searches were developed from the experiences of the New York State Department of Environmental Conservation (Sarah Fernald, personal communication, 19 July 2013) and the California Bureau of Reclamation Tracy Fish Collection Facility (ANSTF 2003).

- Look below the first barrier in the system, such as a dam or weir.
- Check quiet pools at the creek edge and look for leg movement in areas with leaf litter.
- Look for dorsoventrally flattened (oblong) burrows along stream banks.
- The best time to spot the crab is during the adult migration downstream into estuaries from freshwater (late summer/fall) or the juvenile migration upstream to freshwater (spring).
- Exoskeletons are found more often than the crab itself.
- Crabs tend to move at night, so periodic night surveys, especially during migration periods, are more likely to result in spotting crabs than daytime searches.
- Crabs are typically not found in the water column and will be found moving along the bottom and sides of waterbodies.
- Knowing where crabs may be present throughout the year also assists with identifying potential volunteers for passive monitoring (Table 5).

Other precautions include the handling any live-caught crabs. If a Chinese mitten crab is found, it is imperative that the crab is not thrown back into the water alive. The spotter should take a close-up photo of the crab and note the precise location where the animal was found. The crab should be frozen or preserved in alcohol and the appropriate state/provincial agency should be contacted. The contact information for reporting crab sightings can be found on the Mitten Crab Watch Card in Appendix II and the NEANS web site. Taxonomic experts (identified via NEANS) should be consulted to verify and confirm each new sighting that is reported.

Table 5: General monitoring guidelines.

Time of Year	Habitat	Method
Late summer/fall	Downstream migration out of river into estuarine water	Visual surveys, fyke nets, seine nets
Winter	Deeper marine water	Trawl bycatch, trap bycatch, seine nets
Spring	Upstream migration into river	Visual surveys, fyke nets, seine nets

Passive Monitoring

Passive monitoring builds upon the efforts of people working in habitats where mitten crabs may be found, including members of recreational boating associations, shellfishermen, aquaculturists, harbormasters, and volunteer monitors/citizen scientists collecting data as part of other projects.

Sharing the monitoring criteria with individuals conducting ongoing monitoring efforts (e.g., anadromous fish counts) is one example of the outreach efforts that targets a group working in potential mitten crab habitats. An example of ongoing passive monitoring programs in the Northeast is the Marine Invader Monitoring and Information Collaborative (MIMIC), which is coordinated by the Massachusetts Office of Coastal Zone Management. MIMIC was established in 2006 to serve as an early detection network for marine invasive species throughout New England by training volunteers to identify invaders. MIMIC developed a protocol document, "Monitoring Marine Invasive Species: Guidance and Protocols for Volunteer Monitoring Groups" (http://www.mass.gov/eea/docs/czm/invasives/mimic-guide-2011-web.pdf). This method focuses on monitoring locations associated with shipping, such as ballast water and boat hulls that are primary vectors of transport for many invasive species. This approach suggests monitoring locations such as marinas and floating docks, cobble shores and tidepools. Each volunteer group selects its own sites for monitoring during the course of the year.

Salem Sound Coastwatch (SSC), a non-profit organization devoted to the protection of the Salem Sound, Mass., watershed has another good example of an ongoing passive monitoring program. In 2004, SSC developed their own protocol (http://www.salemsound.org/PDF/SSCW_MIS_Monitoring_Guide.pdf) to work with volunteers to collect quantitative data on marine invasive species from a variety of habitats. The SSC continues to train volunteers to use the protocol for the early detection of marine invasive species. In addition, SSC has developed a series of marine invasive species identification cards, including one for the Chinese mitten crab (http://www.salemsound.org/misID.html and Appendix II).

Active Monitoring

Active monitoring involves professionals or volunteers conducting systematic surveys to detect the presence of mitten crabs. Active monitoring may be focused in areas where introductions are likely, such as near pathways of introduction, or in sensitive habitats where impacts are likely to be great or invasion is likely to be rapid (Worral 2002). For those interested in starting a monitoring program, the Northeast Sea Grant College Programs Northeast Marine Introduced Species (NEMIS) website (http://nemis.mit.edu/index.php) is a valuable resource for guidance on species of concern and their pathways of introduction, information on how to get involved in volunteer monitoring and access to outreach and educational materials.

Outreach

For the successful early detection of the Chinese mitten crab, it is critical that professionals, volunteers and anyone using or working in habitats where the crabs may be found are: (1) aware of how to identify a mitten crab, and (2) know what to do if one is sighted.

To achieve these goals, the Sea Grant Programs from N.H., Maine, and the Mass. Institute of Technology (MIT) organized and implemented the following outreach efforts (more details can be found in Appendix III):

- outreach presentations
- educational materials for targeted groups of passive and active monitors
- an early detection “Mitten Crab Watch Card” containing identification and reporting contact information
- a PowerPoint presentation available for distribution

Both a centralized system for reporting as well as state agencies and local organizations (for implementing on-the-ground efforts) are needed for fielding early detection information. Currently, all mitten crab sightings are reported to the Smithsonian Environmental Research Center Mitten Crab Watch database (http://mittencrab.nisbase.org/) and regionally collected in the MIT Sea Grant Marine Invader Tracking and Information System (MITIS) database (https://mit.sea-grant.net/mitis/). Data reported to MITIS are made available online through the NEANS Panel as well as individual and regional Sea Grant Programs. Given ongoing challenges with designated staff capacity within local, state and federal agencies for addressing marine invasive species issues, the NEANS Panel plays a critical role in achieving central coordination and communication goals. The NEANS Panel, which convenes quarterly, provides a forum for sharing information about the Chinese mitten crab to its members that include state, provincial and federal agencies, as well as Sea Grant representatives, non-government organizations, academics and others.

Available information and outreach resources related to Chinese mitten crab awareness and monitoring are listed in Table 6. Examples of some of these outreach materials can be found in Appendix II. A summary of example outreach activities that were completed as part of a regional Chinese mitten crab project funded by the National Sea Grant program is listed in Appendix III.

Table 6: Chinese mitten crab outreach resources.

	Source	**Content**	**Location**
Federal	Northeast Aquatic Nuisance Species Panel	Online field guide/fact sheet	http://www.northeastans.org/online-guide/species-information.html?SpeciesID=8
	U.S. Aquatic Nuisance Species Task Force	Fact sheet	http://anstaskforce.gov/spoc/mitten_crab.php
	U.S. Geological Survey	Database of sightings and distribution maps	http://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=182
	Fisheries and Oceans Canada	National website with identification, impact and prevention information	http://www.dfo-mpo.gc.ca/science/environmental-environnement/ais-eae/species/chinese-mitten-crab-eng.html
Regional	Smithsonian Environmental Research Center	Mitten Crab Watch Program	http://mittencrab.nisbase.org/
	N.H., MIT and Maine Sea Grant Programs	Mitten Crab Watch Card	Appendix II
	Gulf of Maine Research Institute	Vital Signs Program Species Card	http://vitalsignsme.org/sites/default/files/content/fci_chinesemittencrab_113015_0.pdf and Appendix II
	N.H., MIT and Maine Sea Grant Programs	PowerPoint slides	Found of on each of Maine, N.H. and MIT Sea Grant websites
	Northeast Marine Introduced Species	Regional website with protocols and prevention information	http://nemis.mit.edu/index.php
	The Prince Edward Island Aquaculture Alliance	Website on aquatic intruders, including the mitten crab	http://www.aquaticintruders.com/

Rapid Response

Rapid response efforts are designed to contain or eradicate an invasive population and mitigate its impacts. Science-based decisions must be made quickly in order for rapid response efforts to be successful, effective and environmentally sound. Further, information associated with the expected impacts and response to the invasion must be disseminated to all relevant stakeholders clearly and efficiently, and prior experiences should be used to guide these efforts (NISC 2003). Due to the time-dependent and complex nature of rapid response efforts, it is critical that a well-coordinated progression of events occurs. Some states and provinces in the northeastern U.S. and eastern Canada are developing (or have developed) state specific guidelines for rapid response planning. Links to state/province specific resources or examples can be found in Appendix IV.

Because officials with regulatory authority and the chain of command vary by state/province, a general progression of rapid response actions is presented that can be further modified as necessary (Figure 7). Details of each stage of rapid response are described below. Although the process is depicted as a linear progression, often the stages of response will overlap or occur simultaneously.

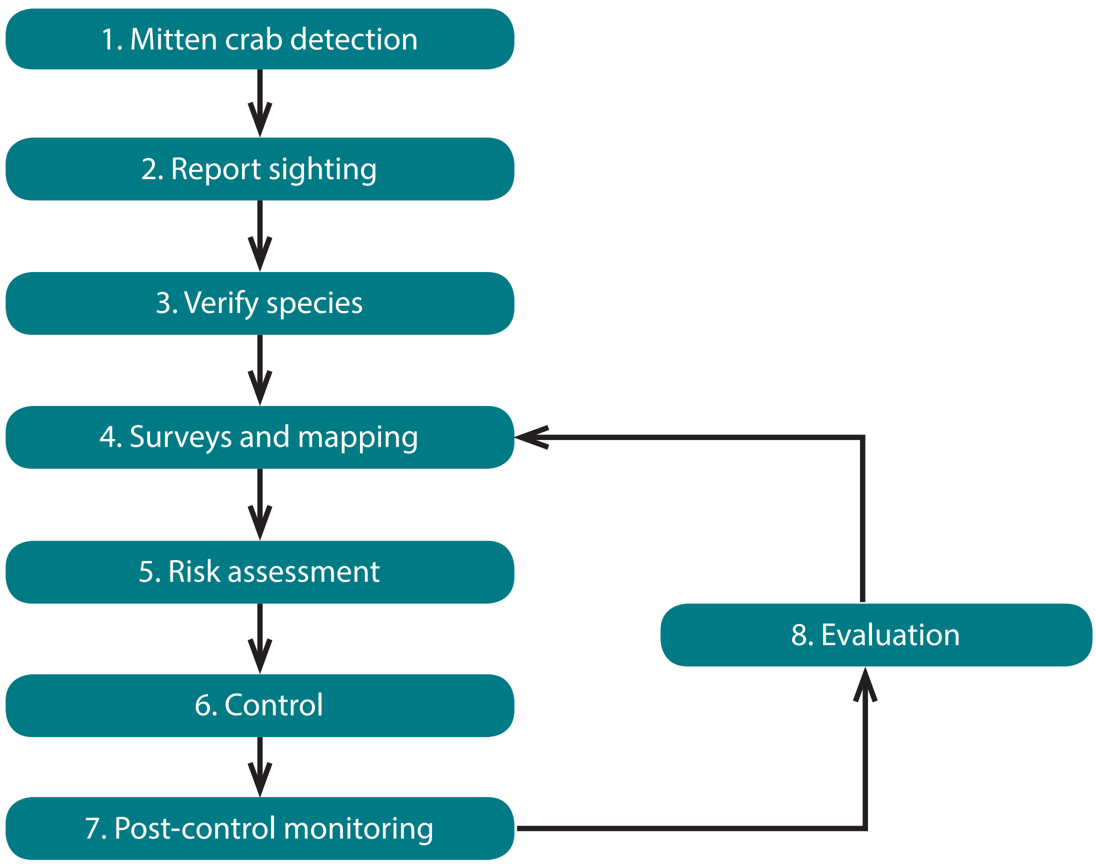

Figure 7: A flow diagram for the steps of an early detection and rapid response effort (based on NEANS 2013).

It is critical to establish a lead agency in each state/province (as we have done) to take on the responsibility of administering the rapid response process. Other partners may be involved or the lead agency may designate other organizations to confirm or work on a rapid response. If multiple agencies and organizations are used in a response then the Incident Command System (ICS) should be used. Resources for ICS training can be found at http://www.anstaskforce.gov/ics.php.

Effective communication and outreach is a critical component of each step of a rapid response effort. Recommended outreach strategies are provided in the descriptions below.

Mitten Crab Detection

The rapid response process begins with a probable mitten crab detection. Most often just the carapace (rather than a fully intact crab) is found. The person who detects the suspicious specimen should record the following information:

• their name
• where and when the specimen was collected
• specific location coordinates (if possible)
• a description of the location with as much detail as possible (nearby street, house descriptions, etc.)
• contact information
• a photo of the specimen

The specimen should not be returned to the waterbody; it should be collected and frozen or preserved in rubbing alcohol. The sighting should then be reported to the appropriate natural resource agency in each state/province as quickly as possible. Mechanisms are needed to facilitate information sharing and ensure that members of the public know who to contact in the event they discover a new mitten crab. Appendix II includes a mitten crab watch card that can be used for these purposes.

Report Sighting

The initial point of contact for reporting a new mitten crab sighting for each state/province is listed in Table 7 (as well as on the Mitten Crab Watch Card in Appendix II). Experiences in other states suggest that all reports should be filtered to a single individual in each state or province (Grisé 2009). Communications mechanisms should be in place for the natural resource agency staff member who receives the sighting information to notify other state/provincial and federal entities that a positive identification has been determined. Ideally a rapid response procedure specific to each state/province is in place. Appendix IV provides links to existing rapid response plans for individual states and provinces. A taxonomic expert should verify all sightings. The state/province in which the crabs were sighted should survey the area to collect samples for positive identification.

Table 7: Contact information by state/province for reporting a Chinese mitten crab sighting.

State/Province	Agency	Phone Number
Quebec	Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs	418.627.8694 x7461
New Brunswick	Aquatic Invasive Species Hotline	1.866.759.6600
Nova Scotia	Aquatic Invasive Species Hotline	1.866.759.6600
Prince Edward Island	Aquatic Invasive Species Hotline	1.866.759.6600
Maine	Maine Dept. of Marine Resources	207.633.9524
New Hampshire	New Hampshire Fish and Game	Salt water 603.868.1095 Fresh water 603.271.2501
Massachusetts	MIT Sea Grant	617.253.9301
Vermont	VT. Dept. of Environmental Conservation	802.490.6121
Rhode Island	Dept. of Environmental Management - Marine Fisheries	401.423.1939
Connecticut	Dept. of Energy and Environmental Protection	860.434.6043
New York	Sarah Fernald	845-889-4745

Sightings can be added to the regional MITIS database through the Hitchhiker's Guide to Exotic Species Portal (http://mit.sea-grant.net/mitis/visitinfo_hh.php?form=visitinfo_hh) or by sending an email to jpederso@mit.edu. In addition, sightings can be reported to iMapInvasives (http://www.imapinvasives.org/), an online tool for reporting invasive species.

Verify Species

The photographs and/or specimen should be verified by a taxonomist who has the expertise to identify the species of the crab. State contacts for species identification and handling information can be found at the Aquatic Nuisance Species Task Force Expert Database (http://www.anstaskforce.gov/experts/search.php). Alternatively, the voucher specimen and sighting information may be submitted to the Smithsonian Environmental Research Center's Mitten Crab Watch Program for positive identification (http://mittencrab.nisbase.org/). The specimen should be handled in compliance with state/provincial/federal regulations regarding the transport of prohibited species. Where resources are available, genetic tools can be a secondary confirmation of the species.

Once a mitten crab specimen has been verified, state/provincial agency contacts should notify the public and the media. Messaging should include potential impacts of mitten crab infestation, what the next steps in response will be and what to do if additional mitten crabs are found. The coordinating lead is responsible for identifying the spokesperson with whom the media will communicate.

Surveys and Mapping

Once a specimen is verified as a Chinese mitten crab, then the waterbody from which it came must be sampled to delineate the full extent of mitten crab range and the potential effects of the infestation. A review of the available literature on methods for capturing Chinese mitten crabs is presented in Table 8. Information on the affected area including a habitat survey, the quantity and life stage of the crab(s) present, hydrologic data, the presence of rare species, possible vectors of introduction and spread and any potential impacts to human uses should be collected and documented. Adjacent waterbodies may also need to be sampled to determine the extent of infestation. Larval screening of the waterbody should be included in the survey, as well as genetic sampling if tools are available.

Cooperating agencies and organizations should be notified and should then decide upon a course of action based on the range and severity of the infestation. Outreach efforts should begin with developing a strategy for informing relevant agencies and identifying key public outreach audiences and gathering relevant information that is targeted for the needs of these audiences. Outreach information should include the current extent of the infestation, the current and planned actions, the personnel involved and the resources needed.

Neighboring states, municipal contacts, the public audiences and the media should be notified as to the extent and severity of the infestation as well as the course of action. The individual who reported the infestation should also be notified of the outcome of their report.

Table 8: Review of methods for capturing Chinese mitten crabs.

Method	Life Stage	Habitat	Notes	Reference
Recommended				
Block net enclosure with beach seining depletion	Juveniles, adults	• Shallow intertidal and subtidal areas • Can be used in dense submerged vegetation but not recommended for emergent vegetation	• Low catch rates	Veldhuizen et al. 2002
Crab condo (2" pipe arranged vertically in a crate, covered on all sides and bottom with netting and left open at the top)	Juveniles	• Megalopae can settle within dense emergent or submerged aquatic vegetation, shallow and deep waters, strong current, fine sediments	• Open top allows crabs to leave structure • Need to be picked up vertically and quickly • Additional weight needed if in strong current • High success rates observed with differing set times (two weeks and 48 hours)	Veldhuizen et al. 2002; Hewitt and McDonald 2013
Burrow census	Juveniles	• Tidally influenced sections of streams with silty banks exposed during low tide	• Only effective once population has been established	Veldhuizen 1997; Veldhuizen et al. 2002
Needs Further Evaluation				
Star trap (crab tap where four rigid sides fold up to form a pyramid)	Adults; possibly juveniles depending on mesh size	• Shallow water • Slow current	• Needs further evaluation and design modifications (e.g., smaller mesh and additional weight) • Caught no crabs with sardine bait	Veldhuizen et al. 2002
Snare trap (bait cage with monofilament snares that can be cast with a fishing rod)	Adults	• Slow currents • Slack tide preferred	• Attaching a single whole sardine to outside of trap was more successful than filling the trap with frozen sardines	Veldhuizen et al. 2002
Otter trawl	Adults; possibly juveniles depending on mesh size	• Open water	• Vegetation causes clogs • Snags on rocky outcrops or structurally complex environments	Veldhuizen et al. 2002; Hewitt and McDonald 2013
Crab pot	Juveniles, adults	• Dense emergent or submerged aquatic vegetation • Shallow and deep waters • Strong currents (additional weight needed)	• Small sample size in trial (n=1) • Considered similar to bait traps so may not be effective for mitten crabs	Veldhuizen et al. 2002

Table 8, continued: Review of methods for capturing Chinese mitten crabs.

Method	Life Stage	Habitat	Notes	Reference
Needs Further Evaluation				
Fyke net	Juveniles, adults	• Rivers and streams	• Researchers at The Natural History Museum (UK) are currently evaluating modifications that would limit/prevent bycatch of eels	http://www.nhm.ac.uk/research-curation/life-sciences/invertebrates/research/crustacea/mitten-crab/fyke-net-trials/index.html
Not Recommended				
Baited traps	Adults	• Dense emergent/submerged aquatic vegetation • Shallow and deep waters • Strong currents (additional weight needed)	• Very low success rates despite evidence of crabs • Not effective where crab densities are low • Not appropriate for juveniles due to their herbivorous diet • Bycatch is a problem (turtles and river otters were attracted to bait)	Veldhuizen 1997; Veldhuizen et al. 2002; Hewitt and McDonald 2013
Modified crayfish trap	Adults	• Slow current	• High escapement despite modifications to funnel entrance	Veldhuizen et al. 2002
Ring net	Adults	• Shallow water • Slow current	• Low catch rates despite high density of crabs in the area • Presume high escape rates in deep water	Veldhuizen et al. 2002

Risk Assessment

A species risk assessment is based on the mitten crab's life history, level of invasiveness, the size of the infestation, the control technologies available and the ability of the lead agency and partners to bring to bear the resources necessary to control the infestation. In addition, the technical, political and financial feasibility will influence any response.

The selection of an appropriate control strategy requires careful consideration of the potential efficacy of the method as well as possible unintended impacts. When selecting a control strategy, the following factors should be considered (NEANS 2005):

- The goals of the control measure (e.g., to prevent ecological harm, protect human health, maintain ecologic value, reduce the risk of spread)
- The potential toxicity of the control measure
- The hydrologic/physical characteristics of the waterbody (e.g., size, depth, flow, connectedness)
- The biological characteristics of the waterbody (e.g., potential short/long term impacts to biological community, presence of rare species)
- The human uses of the waterbody and potential impacts to its value (e.g., water supplies, recreation)
- The likelihood of control strategy success
- Risks associated with a given control type versus no control
- Permits required by state/province

Control

If at any point in the control response it is determined that quarantine/containment is not feasible, then spread prevention measures should be pursued.

Quarantine/Containment Procedures

Quarantine procedures are used to limit the spread of mitten crabs to additional areas of a waterbody or to adjacent waterbodies and the procedures vary among provinces and states (Table 9). Based on the habitat survey, if quarantine is warranted and feasible, the appropriate authorities for implementing the quarantine should be identified based on habitat type (freshwater and/or marine habitat) and property ownership. Quarantine procedures may involve the installation of temporary barriers in a waterbody as well as the restriction of activity (e.g., boating, fishing, swimming) to limit/prevent the spread of mitten crabs. In some states/provinces, permits may be required to install barriers (Table 9).

Once an organism is detected, it is important that quarantinie efforts are instituted to attempt to limit its spread. The likelihood of quarantine success is greatest in systems with low connectivity, and thus decreased potential for rapid spread over large areas. That said, given the mitten crab's complex life history that includes a relatively long larval stage and a cryptic adult life, there is a low probability that quarantine measures will be effective. Each infestation event will require assessments to set priorities for control and management efforts that will achieve the goals of quarantine and control. As noted earlier in the document, given the low likelihood of success of quarantine, prevention is the most effective way to manage and control crabs.

It is important to conduct outreach to local residents and explain why the quarantine is in place in order to generate community support and understanding for the efforts. Outreach will also increase success of enforcement efforts to restrict or limit human access to or from an infected waterbody.

Table 9: Permits required for quarantine efforts.

Location	Action requiring permit	Permit required	Contact
Maine	Barrier installed for longer than seven months	Natural Resources Protection Act	Maine Department of Environmental Protection
Vermont	Closure of lakes, ponds or reservoirs to boating	Vermont Use of Public Water Rules (subsection (g) of Section 4.1)	Secretary of the Vermont Agency of Natural Resources
Federally navigable waters (U.S.)	Limitation of access to federally navigable waters	Captain of the Port Order	Northern New England Sector of the United States Coast Guard
Navigable waters of the U.S.	Work and structures in navigable waterways including the use of fill, dams and dredging	Safe Rivers and Harbors Act (section 10); Clean Water Act (section 404)	United States Army Corps of Engineers
Canada	Limiting or closing access to a waterbody	http://www.dfo-mpo.gc.ca/pnw-ppe/index-eng.html	Fisheries Protection Program of the Department of Fisheries and Oceans Canada

Implement Control Efforts

The elusive nature, cyclical population structure and wide range of physical tolerance of mitten crabs present many challenges to their control. As such, in areas where mitten crabs have successfully invaded, complete eradication may not be an achievable goal. In this case, natural resource managers may opt to focus on ecological control, where the goal is to bring population numbers down to levels where they do not negatively impact the ecological functions of the system. Regardless of approach, control will require continued coordination and communication among federal, state and local entities, and a commitment of staff and monetary resources. Prior to initiating a control strategy, sufficient public support is necessary; therefore, public outreach is a key component of control efforts (see the outreach section below for examples of strategies).

Table 10 presents a summary of the literature about potential control strategies. Many of the methods have been tested in regions where the mitten crab has invaded, and more information about the method can be found in the references.

Table 10: Potential methods for control of Chinese mitten crabs.

Method	Status/Effectiveness	Considerations	References
Physical Controls (e.g., traps, trawls, barriers)	• Most effective during migration • Traps placed upstream (juvenile migration) or downstream (adult migration) of dams/weirs; overall population control is unknown • Electrical screens can be placed on the river bottom in areas where crabs congregate; effectiveness is unknown • See Table 8 for a review of specific trapping methods	• May need to occur at a large scale (i.e., multiple tributaries) to effectively reduce population • Potential for bycatch of non-target species • Likely not effective in large waterbodies with a high degree of interconnectedness	Panning 1939; Halsband 1968 cited in USFWS 1989; ANSTF 2003, Rudnick 2003
Commercial Harvest	• Adult crabs are highly valued food; economic incentive • Commercialization can reduce abundance with minimal cost but may increase the risk of spread	• Public health implications are unclear (e.g., bioaccumulation of contaminants, pathogens) • Smaller crabs are less marketable so may not be effectively controlled • May increase the risk of spread (both intentionally and unintentionally) • Promoting mitten crabs for their economic value may decrease understanding of the need for their control	Hymanson et al. 1999; Zhao 1999; Rudnick 2003; Clark et al. 2008; Hui et al. 2005
Exclusion devices associated with intake structures	• Barriers installed along intake channels to divert crabs from a fish facility were used in Calif. with unknown results • Rotating "Grizzly" screens to allow water, but not crabs, to pass were 80% effective at removing crabs from the Tracy Fish Collection Facility (Calif.)	• Potential considerations will vary on a case-by-case basis. Appendix D of ANSTF 2003 provides a comprehensive overview of exclusion device considerations. • Good potential for managing large crab populations	ANSTF 2003
Biological Control (e.g., predators, pathogens, parasites)	• No known biological control specific to the mitten crab • Predator-prey control is presently not a viable option	• Potential impacts to non-target organisms	Panning 1939; Hoestlandt 1948; ANSTF 2003; Rudnick 2003
Physiological controls (e.g., chemical inhibitors; chemical disruptors)	• Currently no data		

Post-Control Monitoring

Given the demonstrated difficulty in controlling mitten crabs, a monitoring program is critical to understanding whether control goals are being met and to identify any unintended impacts. The monitoring activities, time-frame and the entity responsible for monitoring should be determined simultaneously with the development of the control plan.

The section on active and passive monitoring highlights some of the criteria for surveys of potential habitats. These criteria include identifying potential vector areas, selected habitats for the different life history stages and a process for reporting relevant information to contacts. Increased monitoring of areas where crabs or their exoskeletons have been found will be tailored to the site and the resources available. Identification of high-risk and moderate-risk estuaries based on temperature, salinity and large estuarine characteristics of watershed area, estuary size, tidal intrusion, flushing time and salinity optimum for larvae suggest that estuaries from N.H. and to the south are likely to support crab populations (Table 4). Data for several of the criteria are not known for all estuaries in the Northeast, thereby limiting the ranking and risk of infestation analysis. Monitoring for basic hydrological data should be included in order to meet the management and control goals.

Evaluation

After the control measures have been implemented and monitoring data have been collected, a report should be prepared to document the efficacy of the rapid response effort. Evaluation of control activities will allow for an adaptive approach to managing mitten crab populations. The report should detail the financial resources needed to implement control measures, including the cost of equipment, personnel and any other associated costs. Monitoring data should be analyzed to document the success, failure or continued needs of the control efforts. Unintended impacts, including those to the native aquatic community, should also be documented.

The evaluation should provide the information to guide next steps in the response, including the modification/abandonment of control strategies and reassessment of the situation (Figure 7) to achieve improved results. The report should also provide lessons learned to help guide future planning and response work.

Outreach

The effectiveness of a control program is contingent on effective communication and public participation, therefore it is critical that outreach efforts be integrated at each step. Once a mitten crab is confirmed and the size of population investigated, the public should be notified to explain the extent of the infestation, the potential economic and environmental impacts of established of mitten crab populations and the next steps that will be taken. As noted above, especially in the early stages, the coordinating lead should be responsible for providing the initial media press releases and comments to minimize confusion. As the efforts progress, other outreach activities will expand information sharing.

Prior to initiating control measures, it is recommended that a public meeting be held by the lead agency to provide information on the problem, how it is being addressed, how the control measure was selected and the timing of control operations and potential impacts. This type of event is also an important opportunity for the public and decision-makers to ask questions and express concerns. Public understanding of the threats of a mitten crab invasion and the efforts to manage it will result in greater public support of control efforts. These outreach efforts can build on the work by agencies, non-government organizations and others that are actively and passively monitoring for mitten crabs and those that have access to media contacts and social media networks (e.g., Northeast Sea Grant Programs).

Funding Resources

The availability of funding resources to support early detection and rapid response efforts is generally scarce. The lack of funding opportunities represents a major obstacle to successfully controlling mitten crabs once they are detected.

While some organizations may be able to provide limited amounts of funding, these sources may have restrictions on who can apply and/or how the funds are used. Such funding can often serve to initiate a program, but generally are insufficient to fully implement the coordinated response needed for early detection and rapid response. The NEANS Panel developed a Rapid Response Financial Assistance Program that has supported small projects for its member states and provinces. This program is a model that has not been adopted at the state or national level. Information about what is needed for the NEANS Rapid Response Financial Assistance Program can be found at http://northeastans.org/resources.html.

As part of Executive Order 13653, the Department of the Interior and the National Invasive Species Council are tasked to work with states and tribes to develop a framework for a national Early Detection and Rapid Response (EDRR) Program, including a plan for creating an emergency response fund to address "emerging invasive species issues across landscapes and jurisdictions." As of Fall 2015, a final report is in progress (DOI 2015).

Other potential funding sources exist that are not specifically dedicated to early detection and rapid response efforts (e.g., Sea Grant Program Development Funds, Coastal Zone Management Funds). These funds are generally related to natural resource management and may be appropriate depending on funding availability and priorities in a given funding cycle. It is recommended that state/provincial agency contacts be consulted to see what the best options are for each state/province.

Research and Management Needs

Many data gaps remain with regards to the life history of the mitten crab. Below is a list of priority research needs for the effective management of mitten crabs in the Northeast. Many items in this list were gleaned from the National Management Plan for the Chinese Mitten Crab (ANSTF 2003) and in Rudnick 2003.

1) Ballast water regulations should be effective in limiting larval releases, but areas with known infestations should have special local measures to limit or exclude taking on ballast water in those areas where larvae are present.

2) Molecular techniques that allow for accurate next generation sequencing to detect mitten crab larvae and the presence of adult crabs are high priorities for the region. For example, this could be applicable in the Long Island Sound region where carapaces were found.

3) A better understanding of population fluctuation cycles and understanding the drivers of fluctuations will allow us to determine whether Chinese mitten crab populations in East Coast estuaries are established in the "bust" part of the cycle or not yet established. This issue is most relevant to the Hudson River where crabs continue to be found.

4) Improve hydrologic data (e.g., salinity intrusion, flushing rate and estuarine salinity over time; see Table 3) for the northeastern estuaries that are relevant to determining habitat suitability.

5) In areas where mitten crabs have established, an improved understanding of the dynamics of mitten crab larvae is needed to determine where and when larvae are at high abundances. This information is needed so that appropriate control measures can be planned prior to the mass migration and may be most relevant to the Hudson River area and Long Island Sound were carapaces have been found.

6) In areas with established populations, more information is needed on the settling dynamics of juveniles to understand how they distribute among rivers and streams. This will have important implications for directing control measures.

7) Research is needed to better understand the trophic impacts of mitten crabs on native biota, particularly protected aquatic species.

8) Analysis of the economic impacts of Chinese mitten crab invasion on aquaculture, fisheries and human health is needed.

9) There is a need for enforcement of state and federal regulations. Policy instruments need to be developed to support prevention measures (e.g., states need regulations to supplement the Lacey Act).

Summary

Due to the diversity of habitats occupied by mitten crabs throughout their life history, the potential impacts of established mitten crab populations on the ecosystems and economy of northeastern United States and Atlantic Canada is substantial. This plan provides information needed to support coordinated efforts to prevent and control the spread of Chinese mitten crabs to avoid and mitigate potential impacts. Prevention is without question the most effective approach available to stopping the invasion and spread of mitten crabs. Effective prevention and control efforts will require ongoing communication among local, state and federal partners. Coordinated outreach efforts are needed to raise awareness of mitten crabs and their potential impacts as well as reduce the chances of unintentional introduction. The implementation of the actions recommended in this plan will be a challenge, as they will require funding as well as a commitment of staff time from agencies and organizations. However, by adopting common approaches, coordinating efforts and creating a well-informed public, invasive species professionals can help fight introduction and spread of invasive species such as the Chinese mitten crab.

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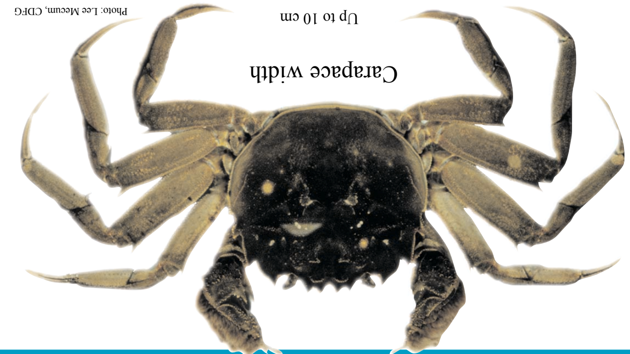
Appendix I: Table of Reported Chinese Mitten Crab Sightings in East Coast Drainages

State/Province	County	Locality	Year	No. of crabs
CT	Fairfield	Mianus River	2014	1
CT	Fairfield	Mianus River	2012	1
NY	Kings	New York Harbor	2010	5
NJ	Hudson	New York Harbor	2010	16
DE	Kent	Delaware Bay	2010	4
DE	New Castle	Delaware Bay	2010	4
NY	Columbia	Hudson River	2009	1
NY	Albany	Hudson River	2009	1
NY	Dutchess	Fall Kill	2009	1
NY	Orange	Hudson River	2009	1
NY	Kings	Hudson River	2009	2
NY	Dutchess	Fall Kill	2009	7
NY	Greene	Hudson River	2009	4
NY	Westchester	Hudson River	2009	1
NY	Rockland	Sparkill Creek	2009	2
NJ	Monmouth	Shrewsbury River	2009	1
NJ	Monmouth	Navesink River	2009	1
NJ	Hudson	Hudson River	2009	1
NY	Orange	Hudson River	2008	4
NY	Dutchess	Indian Kill	2008	1
NY	Dutchess	Hudson River	2008	10
NY	Dutchess	Stony Creek	2008	1
NY	Dutchess	Saw Kill	2008	1
NY	Greene	Catskill Creek	2008	3
NY	Dutchess	Fall Kill	2008	3
NY	Rockland	Hudson River	2008	1
NJ	Ocean	Toms River	2008	1
NJ	Monmouth	Raritan Bay	2008	1
MD	Queen Anne's	Chesapeake Bay	2007	1
NY	Putnam	Hudson River	2007	1
NY	Westchester	Hudson River	2007	1
DE	New Castle	Delaware River	2007	2
DE	Kent	Delaware Bay	2007	1
MD	Calvert	Chesapeake Bay	2007	2
QUE		St. Lawrence River Estuary	2007	2
QUE		St. Lawrence River	2007	2
MD		Patapsco River	2006	1
QUE		St. Lawrence River Estuary	2006	2
QUE		St. Lawrence River	2006	1
MD		Patapsco River	2005	1
QUE		St. Lawrence River	2005	1
QUE		St. Lawrence River	2004	2

Appendix II: Outreach Materials

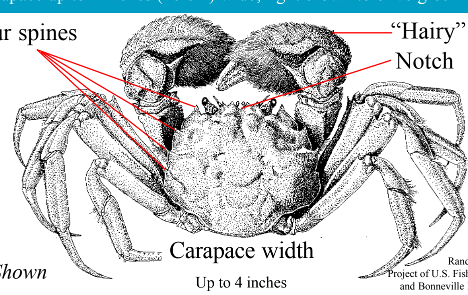
Northeast Regional Sea Grant Programs Chinese Mitten Crab Watch Card



Mitten Crab WATCH

How to Identify a Mitten Crab

- Adult crabs live in fresh waters of North America; juveniles live in estuaries
- Claws equal in size, "hairy" (juveniles may not have "hairy"claws), white tips
- Four lateral carapace spines (last one smaller); notch between eyes
- Carapace up to 4 inches (10 cm) wide; light brown to olive green in color



*Adult Shown

Illustration:
Randall D. Babb, for FWS
Project of U.S. Fish and Wildlife Service
and Bonneville Power Administration

The Mitten Crab

First discovered on the U.S. East Coast in 2007 in the Chesapeake Bay, by 2012 a mitten crab was found as far north as Greenwich, Conn. Native to Asia, mitten crabs may pose a serious threat to freshwater, estuarine and marine ecosystems as well as the economy of the eastern United States. They create burrows that increase erosion and weaken stream banks. In other areas they have invaded, mitten crabs have financially impacted commercial fisheries through bait stealing and preying on fish captured in nets. They can carry the oriental lung fluke, a threat to human health. Mitten crabs are most easily identified by a notch between the eyes and hairy claws on the adults (other identification traits are on the back of this card). Your help is vital to report new sightings and to prevent their spread.

If you catch a mitten crab,

- Do not throw it back alive!
- Freeze it or preserve it in rubbing alcohol.
- Note the precise location where the crab was found.
- Contact your local natural resource management agency:

In Maine, call Maine DMR (207.633.9524)
In New Hampshire, call N.H. Fish and Game (603.868.1095)
In Massachusetts, call MIT Sea Grant (617.252.1741)
In Rhode Island, call DEM - Marine Fisheries (401.423.1939)
In Connecticut, call DEEP (860.434.6043)
In Quebec, call MDDEFP (418.627.8694 x7461)
In New Brunswick, Nova Scotia and Prince Edward Island,
call the Aquatic Invasive Species Hotline (1.866.759.6600)

REMINDER: Know the local rules for transporting mitten crabs!
Mitten crab specimens are needed to confirm sightings, but many jurisdictions have different possession and transport rules. Contact your local natural resources agency for instructions. Never transport live mitten crabs.

2014 Maine, N.H. and MIT Sea Grant programs

Eriocheir sinensis

Chinese mitten crab

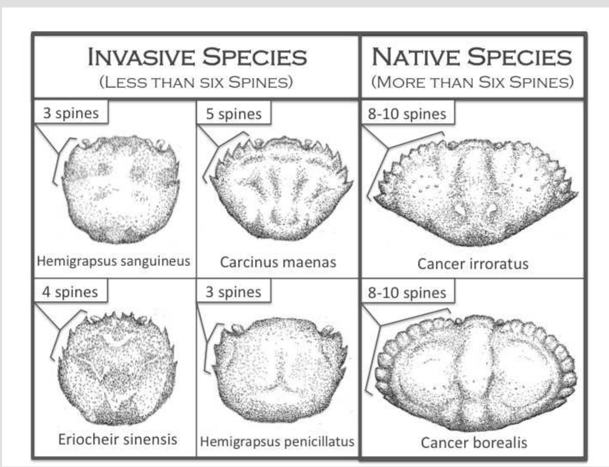
Invasive to Maine

Freshwater & Coastal

Carapace (Shell)

Central Fisheries Board PERMITTED USE

The shell (carapace) has four spines on either side, and reaches a width of approximately 3 inches (80 mm).



Full View

Defrevre Christophe, WoRMS

The main identifying features of the mitten crab are the dense patches of hairs on the white-tipped claws of larger juveniles and adults.

Legs and Claws

Central Fisheries Board PERMITTED USE

The legs of the adult crab are generally more than twice as long as the width of the carapace. The claws are equal in size.

Additional

Eva the Weaver flickr.com

Chinese mitten crabs are omnivores, eating both plants and animals.

www.vitalsignsme.org

Similar Species

The Chinese mitten crab is a cousin of the invasive Asian shore crab but unlike the Asian shore crab, the Chinese mtten crab has small hairs on its claws. It is the only crab in North America that can be found in freshwater.

Fun Fact

The Chinese mitten crab is native to the Yellow Sea in Korea and China. This crab is thought to have arrived from China as larvae in ballast water. Mitten crabs migrate into the sea for reproduction, but spend the rest of their lives in the freshwater.

Gulf of Maine Research Institute

vital signs

Northeast Aquatic Nuisance Species Panel Mitten Crab Information Sheet


Mitten crab (Eriocheir sinensis)
Credit: Christian Fischer

Mitten Crab
Eriocheir sinensis

History
* Between 2005-2008, 19 individuals were confirmed along the U.S. Atlantic coast in the Chesapeake Bay (2005-2007), Delaware Bay (2007), Hudson River (2007-2008), and Raritan Bay and Toms River, New Jersey (2008)
* In Quebec, specimens have been collected from St. Lawrence River at Notre-Dame-de-Pierreville in 2004 and Quebec City in 2005
* Both females and males have been found, but an established reproductive population in eastern U.S. has not been confirmed as of the summer of 2008

Characteristics
* Light brown to olive green
* Carapace (shell) up to 4 in (10 cm) wide
* 4 lateral spines on each side of carapace
* Notch between the eyes
* Claws hairy with white tips
* Claws normally equal in size
* Legs longer than twice the carapace width

Habitat
* Estuaries, lakes, riparian zones, water courses, wetlands
* Burrows in the bottom and banks of freshwater rivers and estuaries
* Tolerates wide range of temperatures
* Catadromous life cycle: begins as estuarine larva, migrates into
freshwater streams for 1-4 years, then returns to coast to reproduce
* Able to survive in highly polluted aquatic habitats
* Adept at walking on land and around barriers

Known Distribution
* Native to east Asia
* Chesapeake Bay, Delaware Bay, Hudson River, New Jersey, Quebec

Impacts
* Efficient predator and competitor for foodl; may have a profound effect on native biological communities
* Damage to fishing gear
* Clogged pumps, screens, and intake pipes
* Burrowing activity may accelerate erosion of banks and levees

GUIDE TO MARINE INVADERS
IN THE GULF OF MAINE

Eriocheir sinensis

Chinese mitten crab

Potential Invader

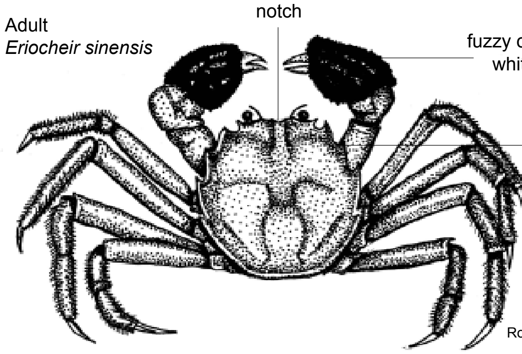
Lee Mecum, CDF&G

PHYSICAL DESCRIPTION

- Dense fuzzy patches on claws of adults and larger juveniles (>1 inch)
- Regenerated claws and claws of smaller juveniles may not have fuzz
- Claws are equally sized and white-tipped
- Four lateral spines on each side of carapace (shell); notch between the eyes
- Carapace light-brown to olive green color; width up to 4 in (10 cm)
- Sharp-tipped walking legs of adult over twice as long as carapace width

HABITAT PREFERENCE

- Catadromous life cycle: begins as estuarine larva, migrates into freshwater streams for 1-4 years, then returns to coast to reproduce
- Burrows in the bottom and banks of freshwater rivers and estuaries
- Tolerates a wide range of temperatures
- Able to survive in highly altered and polluted aquatic habitats
- Adept at walking on land and around barriers
- Nondiscriminating omnivores that consume plants and prey on fish and benthic invertebrates (clams, worms, shrimp)



Rob Gough

1 2 3 4 5 6 7 8

Appendix III: Summary of Outreach Activities

From 2012- 2015, the Maine, New Hampshire and MIT Sea Grant Programs received funding from the National Sea Grant Office to create an early detection network for the Chinese mitten crab. Below is a summary of the outreach activities associated with that project to date.

Target states:

- Maine
- New Hampshire
- Massachusetts

Outreach materials:

- Watch card (Appendix II)
- Powerpoint slides
- Magnets
- Waterproof containers

State	Target Audience	Group Name	Activity
Maine	Volunteer monitors	MIMIC	Use slide deck in talks
Maine	Volunteer monitors	Vital Signs Program, Gulf of Maine Research Institute	Project information included in mitten crab mission
Maine	Volunteer monitors	Casco Bay Estuary Partnership Monitoring Group	Use slide deck in talks
N.H.	Natural resource managers	N.H. DES Watershed Management Bureau Monitoring Programs	presentation
Maine	Natural resource managers	Maine Marine Invasive Species Collaborative	Watch cards
N.H.	Volunteer monitors	Coastal Research Volunteers	presentation
N.H.	Volunteer monitors	UNH Marine Docents	presentation
N.H.	Volunteer monitors	N.H. Rivers Council Seacoast River Runners	presentations
N.H.	Volunteer monitors	Oyster Conservationists	Watch cards in training packets
Mass.	Volunteer monitors	MIMIC	Watch cards
Mass.	Volunteer monitors	Salem Sound Coastwatch	Watch cards, slide deck
Mass.	Volunteer monitors	Center for Coastal Studies	Watch cards
Mass.	Volunteer monitors	Coalition for Buzzards Bay	Watch cards
All	Aquaculturists	Northeast Aquaculture Association	Table at annual meeting
N.H.	Aquaculturists	N.H. Marine Aquaculturist meeting	presentation
Mass.	Aquaculturists	Mass. Aquaculture Association	presentation
Maine	Shellfishermen	Maine Shellfish Advisory Council	presentation
N.H.	Shellfishermen	N.H. DES/N.H. Fish and Game Shellfish Program	presentation
Mass.	Shellfishermen	Mass. Shellfish Officers Association	presentation
Mass.	Shellfishermen	Mass. DMF Shellfish Program	Watch card to be posted on website
Maine	Harbormasters and recreational boaters	State of Maine Harbormaster's Association	presentation
N.H.	Harbormasters and recreational boaters	N.H. Division of Ports and Harbors	presentation
Mass.	Harbormasters and recreational boaters	Mass. Harborsmasters Association	presentation

Appendix IV: State- and Province-Specific Rapid Response Resources

Maine

Rapid Response Plan for Invasive Aquatic Plants, Fish, and Other Fauna – Part 2. Fish and Other Fauna Protocol
http://www.maine.gov/dep/water/invasives/rrp_part2final.pdf

Massachusetts

Rapid Response to Aquatic Invasive Species Introductions
http://www.mass.gov/eea/agencies/czm/program-areas/aquatic-invasive-species/response/

Lake Champlain Basin (Vermont and New York, USA and Quebec, Canada)

Lake Champlain Basin Rapid Response Action Plan for Aquatic Invasive Species
http://www.lcbp.org/wp-content/uploads/2012/08/2009-AIS-Rapid-Response-Plan.pdf

Notes

Notes