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Risk Assessment for Chinese mitten crab (*Eriocheir sinensis*) in Canadian Waters

Évaluation du risque posé par le crabe chinois à mitaine (*Eriocheir sinensis*) dans les eaux canadiennes

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ABSTRACT

Non-indigenous species continue to be dispersed to new environments and in recent decades the Chinese mitten crab (*Eriocheir sinensis*) continues to be introduced to new environments, including the east coast of North America. A risk assessment was undertaken in order to determine the potential risk posed by Chinese mitten crab to Canadian waters, including both the Atlantic and Pacific coasts (and adjacent inland waters). Most global introductions of mitten crabs either have been attributed to commercial shipping activities or intentional introductions (e.g., as a food source). Chinese mitten crab has been reported from several locations in eastern Canada but the extent of the invasion is not well known. Based on impacts of Chinese mitten crab elsewhere and non-indigenous species in general, there is considerable concern about the potential biological, habitat, and genetic impacts if this species becomes established and spreads in Canada. Life history characteristics of Chinese mitten crab could enhance long-distance natural dispersal and further dispersal via ballast water is probable, but a number of other potential vectors exist.

Fisheries and Oceans Canada conducted a national risk assessment to determine the potential risk posed by this non-indigenous crab in Canada. This assessment included evaluating the probability of arrival, survival, reproduction and spread and associated consequences as a measure of risk. In addition, the risk posed by potential pathogens, parasites or fellow travelers (e.g. other invasive species) was evaluated should Chinese mitten crab be introduced. These components were assessed in an expert peer-review workshop held in February 2008 using the best available information on biology, potential vectors of introduction, and impacts in both native and introduced ranges of Chinese mitten crab. The assessment concluded that Chinese mitten crab generally posed a moderate risk on both coasts although habitat impacts such as riverbank erosion were deemed higher risk. For pathogens, parasites or fellow travelers the risks also were moderate. However, as little is known about many potential pathogens, parasites and fellow travelers of this crab species, with the exception of a lung fluke that could infect humans, there was considerable uncertainty about potential hitchhiking organisms.

RÉSUMÉ

Des espèces non indigènes continuent à s'étendre progressivement dans de nouveaux environnements comme c'est le cas, depuis quelques dizaines d'années, pour le crabe chinois à mitaine (*Eriocheir sinensis*) qui s'introduit notamment sur la côte est de l'Amérique du Nord. Une évaluation du risque a été entreprise afin de déterminer le risque éventuel que pose le crabe chinois à mitaine dans les eaux canadiennes, y compris les côtes de l'Atlantique et du Pacifique (et les plans d'eau intérieure adjacents). Si l'introduction de crabes à mitaine n'a pas été faite intentionnellement (p. ex., comme source alimentaire), on l'attribue en général aux activités de navigation commerciale. On a rapporté la présence du crabe chinois à mitaine en plusieurs endroits dans l'Est du Canada, mais l'étendue de l'invasion n'est pas bien définie. En se fondant sur les effets de la présence du crabe chinois à mitaine ailleurs, et des espèces non indigènes en général, les effets possibles sur le plan biologique, génétique et sur l'habitat semblent plutôt préoccupants si cette espèce s'établit et s'étend au Canada. Les caractéristiques du cycle biologique du crabe chinois à mitaine pourraient favoriser une expansion naturelle sur de longues distances et une plus grande dispersion par les eaux de ballast est envisageable, mais il existe un certain nombre d'autres vecteurs possibles.

Pêches et Océans Canada a réalisé une évaluation du risque à l'échelle nationale afin de déterminer le risque éventuel posé par cette espèce de crabe non indigène au Canada. L'évaluation cherchait à établir la probabilité d'arrivée, de survie, de reproduction et de dispersion, de même que les conséquences associées, en guise de mesure du risque. En outre, le risque posé par les éventuels agents pathogènes, parasites ou compagnons de route (p. ex., d'autres espèces envahissantes) a été évalué advenant que le crabe chinois à mitaine soit introduit dans les eaux canadiennes. Ces éléments ont fait l'objet d'une évaluation par des pairs se composant d'experts du domaine dans le cadre d'un atelier tenu en février 2008, au moyen de la plus récente information disponible sur les vecteurs biologiques potentiels d'introduction, et les effets chez les spécimens indigènes et introduits de crabe chinois à mitaine. L'évaluation a permis de conclure que le crabe chinois à mitaine posait généralement un risque moyen pour les deux régions côtières bien que les effets sur l'habitat, notamment l'érosion des rives, étaient jugés à plus haut risque. Quant aux agents pathogènes, parasites ou compagnons de route, ils présentent également un risque moyen. Toutefois, en raison du peu d'information disponible au sujet de nombreux agents pathogènes, parasites ou compagnons de route associés à cette espèce de crabe, à l'exception d'une douve du poumon qui pourrait toucher les êtres humains, il subsiste une grande incertitude relativement aux organismes associés possibles.

INTRODUCTION

Non-indigenous species (NIS) pose an enormous risk to native biodiversity and can compromise ecosystem function (e.g., Sala et al., 2000). In marine ecosystems, crab species have increasing histories of global invasion. For example, the Chinese mitten crab (*Eriocheir sinensis*) invaded Europe in the early 1900s and more recently North America where crabs have been reported from the St. Lawrence River system (Rudnick et al., 2003; Veilleux and de Lafontaine, 2007). Whether or not a non-indigenous species becomes invasive depends on the impact of the non-indigenous species in its newly invaded habitat. The Government of Canada (2004) defines invasive alien species as "those harmful alien species whose introduction or spread threatens the environment, the economy or society, including human health".

In order to characterize the potential risk posed by a new invader to Canadian waters or the spread of an existing invader to additional waters, a risk assessment is conducted. This risk assessment is adapted from the process outlined in the Canadian National Code on Introductions and Transfers of Aquatic Organisms (DFO, 2003) by considering the probability of arrival for unintentional introductions and contains two-parts. Part I evaluates the probability of establishment and consequence of establishment of an aquatic organism while Part II evaluates the probability of establishment and consequence of establishment of a pathogen, parasite or fellow traveler of the aquatic organism. Within each Part of the national framework two component ratings are determined (the probability and consequences of establishment). The final, overall ratings are high (risk is likely, or very likely, to occur), medium (there is probability of negative impact), or low (risk is considered to be insignificant). In addition, a level of certainty or likelihood also is assigned as a gradient from very certain (scientific basis), reasonably certain, reasonably uncertain, to very uncertain ("best guess").

This document summarizes the results of a risk assessment conducted to evaluate the risk posed by non-indigenous Chinese mitten crab if introduced into Canadian waters and contains information for both Atlantic and Pacific coastal waters. The risk assessment process is based upon the best available information for the species. The biological information was obtained from Veilleux and de Lafontaine (2007) who compiled a biological synopsis for Chinese mitten crab. A draft risk assessment document was prepared and peer-reviewed at a workshop attended by international aquatic invasive species and crab experts in February 2008 (see Appendix A for workshop participants). A synopsis of the workshop will be prepared in a separate document to capture discussion at the workshop in addition to key findings. A summary of the Chinese mitten crab's basic biology, native, non-native and potential distribution in Canada, and the risk assessment is provided. In addition, in order to gain scientific knowledge with respect to vectors and pathways and potential impacts associated with non-indigenous crab species, a formal survey of both NIS and crab experts was conducted. The results from this survey help guide the level of risk or uncertainty associated with each step of the risk assessment.

METHODS AND MATERIALS

Risk Assessment Methodology

Risk has two components: probability and impact. The overall level of risk posed by a NIS is a combination of the probability of establishment and the consequences of that establishment. These two scores are combined in a heat matrix (Table 1) to provide an overall risk. Within the probability of establishment there are four major components with each representing a filter in the invasion process that will influence invasion success. The first step in the invasion process is determining the probability that a NIS will arrive to the geographical area being considered by the risk assessment. For example, what potential vectors exist for any given NIS and how frequently is the NIS of concern found within these vectors? The second step is determining if the NIS will survive if introduced. For example, can a NIS find a suitable environment within which to survive? The third step in the invasion process is closely linked with the second but indicates whether or not a NIS that survives the arrival to the new environment can reproduce within that environment in order to establish a sustainable population. The fourth step indicates whether or not a NIS can spread from the initial introduction location. For example, are vectors and pathways available that would allow the NIS to spread to additional suitable environments in its newly invaded range? The second component of the overall level of risk is the consequences of establishment of a NIS. For example, what are the ecological or genetic consequences on native ecosystems or populations if a NIS is able to establish? Risk is characterized both for the aquatic organism (Part I) and potential parasites, pathogens and fellow travelers (Part II).

Table 1: The following summary table was used to determine the overall risk potential by combining the probability of establishment estimate determined in Step 1 with the three consequences of establishment determined in Step 2. In the table Green = Low Risk, Yellow = Moderate Risk and Red = High Risk.

Consequence/ Impact	Very High					
	High					
	Moderate					
	Low					
	Very Low					
		Rare	Low	Moderate	High	Very High
	Probability of Introduction					

Predicting Suitable Environments

The potential future ranges for Chinese mitten crab in Canada were predicted by environmental niche modeling using the Genetic Algorithm for Rule-set Prediction (GARP). Models were constructed using species presence and geo-referenced environmental data. The genetic algorithm developed iteratively a best prediction model, using 80% of occurrence points to train the data, and 20% of occurrence points to test the model. An initial model run, using all possible combinations of the environmental layers, provided each layer's contribution to model accuracy. Only layers that contributed significantly to model accuracy were included in the final predictions, following Drake and Bossenbroek (2004). Environmental variables that contributed significantly to model prediction accuracy were then used to create 100 predictions using a 0.001 convergence limit and a maximum of 1500 iterations (per simulation), following the best subset procedure described by Anderson et al. (2003). The resulting predictions were converted into a map of percentage environmental match using the 'Raster Calculator' in ArcMAP 9.1.

Environmental niche modeling for the Chinese mitten crab was based on two separate sets of predictions for the potential distribution of the Chinese mitten crab based on its native Asian range (Asian model) and its invaded European range (European model). We selected twelve environmental variables with potential distributional importance based upon available datasets with global coverage. Variables considered included ground frost frequency, precipitation, wet day frequency, slope, aspect, topographic index, spring ocean surface temperature, river discharge, mean river temperature, and minimum, mean and maximum air temperature. These were tested for their contribution to model accuracy (as described above), and only those layers which improved model accuracy were included in the final models. The GARP model developed for the native Asian range retained the following layers, each of which significantly improved model fit: precipitation (mm), wet day index (number of days of precipitation), minimum, mean and maximum air temperatures (°C), and compound topographic index (wetness index based on flow accumulation and slope). By contrast, the GARP model based upon the European distribution retained minimum, mean and maximum temperature, wet day index, precipitation, topographic index, and river discharge. The availability of an extensive dataset in the European invaded range allowed an independent validation of the Asian model, assessing its predictive accuracy for the European range. Only 3.7% of European reports were in areas predicted by 50% or fewer of the Asian environmental niche models. Conversely, 84% of occurrence reports were in areas predicted as suitable environment by >80% of GARP models (Herborg et al., 2007a).

In order to distinguish between freshwater habitats in which mitten crabs can survive versus those in which they can establish (i.e., return to the sea to reproduce), we developed a dispersal distance layer in the ecological niche model. We measured the distance between locations of reported occurrence and the nearest waterbody with ≥15‰ salinity using the European data set and the Spatial Analyst tool in ArcMAP 9.1. This dispersal distance was calculated as the shortest path downstream following the river course. Where distances were measured across large water bodies with ≥15‰ salinity (Eastern Baltic Sea), the shortest possible route was taken. The maximum distance of reported occurrence was 1260km from the sea (≥15‰). We also identified the 90th percentile (354 km) for the distribution of inland dispersal distances in Europe. This limit was selected since we believe it captures the areas with significant mitten crab populations. We therefore applied the 354km distance as cut-off points for maximum expected dispersal distances for crabs in major North American rivers (Herborg et al., 2007b).

Expert Survey: Vector Importance

The importance of several potential transport vectors for the dispersal of this crab species were identified through an expert web-based survey. An online questionnaire was designed and sent to 520 experts and three mailing lists associated with either crabs or invasive species. Each respondent was asked to identify their geographic area of expertise, their scientific background and area of expertise. A total of 143 experts visited the questionnaire (but actual responses to each question were less), identifying the importance of ten potential vectors for dispersal: larval drift, directed adult migration, dispersal of adults attached to flotsam, ballast water, hull fouling on ships, movement of aquaculture gear and stock, boating (including trailering), intentional release for establishment (e.g., for food), related to fishing activities (entrapment in gear or shipping materials), via canals or other artificial waterways, as well as by "other" means (undefined). The survey was divided into two parts so that the respondents could differentiate between vectors important for primary establishment as well as for secondary spread. Respondents were asked to provide an estimate of the importance of each vector and the uncertainty associated with their estimate depending on the source of information they used to form their judgment. For both set of questions they were provided a choice of five categories: very high, high, moderate, low, and very low. Definitions for each category were provided with each question (Appendix B), including those of uncertainty. Vector importance and uncertainty are thus discussed in general terms of being either low (very low and low), moderate, or high (high and very high).

Transport Vectors

Literature reports have identified ballast water transport as the primary vector for global introductions of Chinese mitten crab. This vector also was identified as important for secondary spread of this species. Thus, total discharge of ballast water into Canadian ports was estimated based on the Canadian Ballast Water Database Application (CBWDA), developed by Fisheries and Oceans Canada and Transport Canada. This database contains discharge coordinates and volumes obtained from ballast water reporting forms that were voluntarily submitted to the Canadian Coast Guard and individual ports, mainly by commercial vessels entering Canadian waters from outside the Exclusive Economic Zone (EEZ). Data from 2005, which provided ballast discharges for 13 587 of 25 841 ship arrivals for which forms were submitted, was analyzed. The number of arrivals and volume of ballast water discharges were categorized into three major regions (Pacific coast, Great Lakes-St. Lawrence, and Atlantic coast), tabulated and mapped.

Additional potential vectors for initial arrival or secondary spread were identified as potentially important in our survey. We gathered spatially explicit information on the distribution of these transport vectors where it existed. Aquaculture site information was gathered for both coasts from government agencies, aquaculture associations, and scientists and was converted into point data that was then transformed into density maps using ArcMAP 9.1. Thus, it was possible to reflect the density of aquaculture sites in a particular area. Similarly, we used the distribution of small craft harbors (east coast) or small craft harbors, anchorages, ports and marinas (west coast), depending on data availability, as a proxy for small craft vessel traffic. The frequency of different types of large commercial vessels, fishing boats, and barge movements on the west coast was determined based ship traffic data for 2003 (courtesy of the Canadian Marine Communications and Traffic Services [MCTS]). The frequency of vessel movements through a particular area was converted into density layers as above. Due to the absence of suitable data a similar analysis could not be conducted for the east coast.

Potential Impacts of an Introduction: Expert Survey

The importance of several potential impacts due to Chinese mitten crab were evaluated via the same expert web-based survey as were used to evaluate the importance of vectors (see above). Respondents were asked to estimate the importance of each impact and the likelihood of occurrence. Respondents had a choice of six answers for effect levels: positive, very low negative, low negative, moderate negative, high negative, and very high negative, and five levels for the likelihood of an effect occurring: unlikely, possible, likely, almost certain, and certain. Definitions for each category were provided with each question (Appendix B). There were three potential areas of impact that we identified but were not explicitly considered in our expert survey. These included impacts on wildlife or human health, habitat impacts, and genetic impacts. For these types of impacts we relied on literature reports and personal observations/knowledge.

To ease interpretation and discussion, the qualitative measures used to describe the potential of various effects were assigned ordinal values ranging from -1 (positive) through 4 (very high negative). Means for each potential impact were then calculated based on the individual observations thus coded, and divided into 6 equal sized bins (0.833) for an overall score. This provided a balanced view of the potential impacts across the ten impact categories included in the survey. Since generating the mean of categorical variables can be problematic, we also tested the median and mode of the data. Since the mean category for each impact level was very similar independent of the method used, we present only the results of the mean values here.

RESULTS

Ballast Water

In 2005, the majority of ballast water was discharged on the Atlantic coast (29,390,717MT) compared to the Pacific coast (8,515,707MT). The Great Lakes-St. Lawrence region received the lowest volume (1,817,019MT) of ballast discharge. It is important to note that mandatory reporting of ballast water (other than for vessels destined for the Great Lakes – St. Lawrence Seaway) was not initiated until June 2006, thus the 2005 data likely represents incomplete reporting as this was a voluntary period. Further, there will always be some uncertainty with respect to ballast water reported and actual ballast water discharges.

On the Atlantic coast, the largest volume was discharged in Point Tupper, followed by St. John, Come-by-Chance and Sept-Iles (Figure 1), providing potential introduction sites for Chinese mitten crab. The combined ballast water discharged in these three ports exceeds all other ballast water discharges in Newfoundland and the northern Gulf of St. Lawrence combined. Further, Come-by-Chance may see increased vessel traffic owing to changes in oil production and distribution via this port. On the Pacific coast, only Vancouver and the associated Roberts Bank and Fraser Port received a large volume of ballast water (Figure 2) but with increased development of ports in northern British Columbia (e.g., container port in Prince Rupert and tanker port in Kitimat) this could change in the future (Figure 2). The main ports for ballast water discharge in the Great Lakes were in Quebec, Montreal and Sorel, all in the lower parts of the St Lawrence River. Nevertheless the amount of ballast water discharged in these locations is an order of magnitude lower than in the major ports on both coasts (Figure 3).

Other Potential Vectors: East Coast

A number of potential secondary vectors exist on the east coast including aquaculture-related transfers, recreational or small craft traffic and commercial shipping activities, including ballast water movements. However, we were unable to quantify this vector as we were for the west coast (see below) due to unavailable data. In Atlantic Canada, the greatest density of aquaculture facilities is in waters around PEI (Figure 4). Many lower density sites exist scattered around Newfoundland, Nova Scotia, New Brunswick (both near St. Andrews in the Bay of Fundy and on the Atlantic coast) and the Magdalen Islands (Figure 4). Most of the small craft harbors exist around the island of Newfoundland (Figure 5) but this could represent an artifact in the available data as other parts of the Maritimes have much higher population densities. Other higher density areas exist around southwestern Nova Scotia and New Brunswick (mouth of the Bay of Fundy), around Cape Breton Island, PEI and the Magdalen Islands (Figure 5).

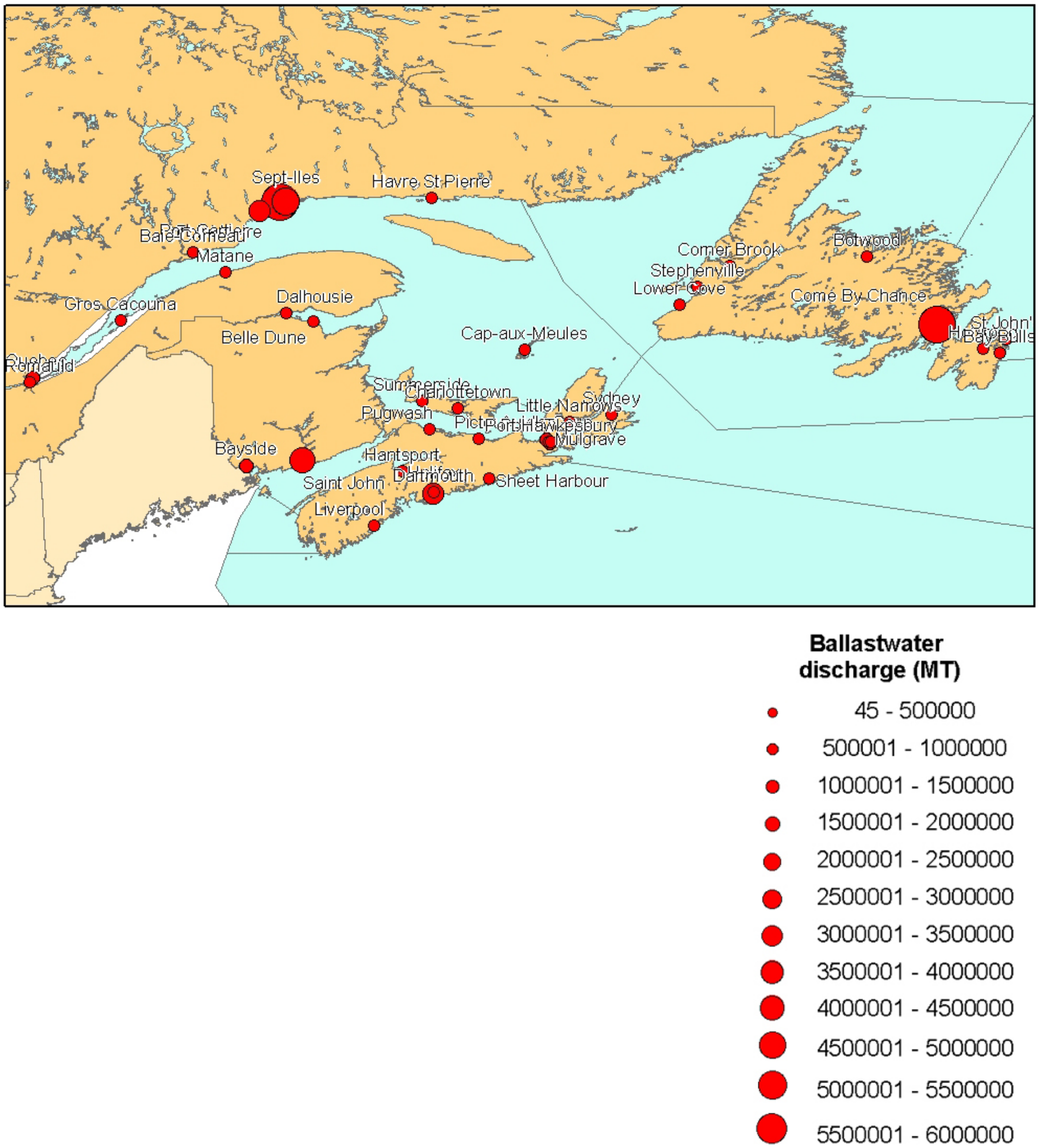

Figure 1: Total ballast water discharge volumes (in megatons, MT) on the Atlantic coast, based on 2005 CBWDA data.

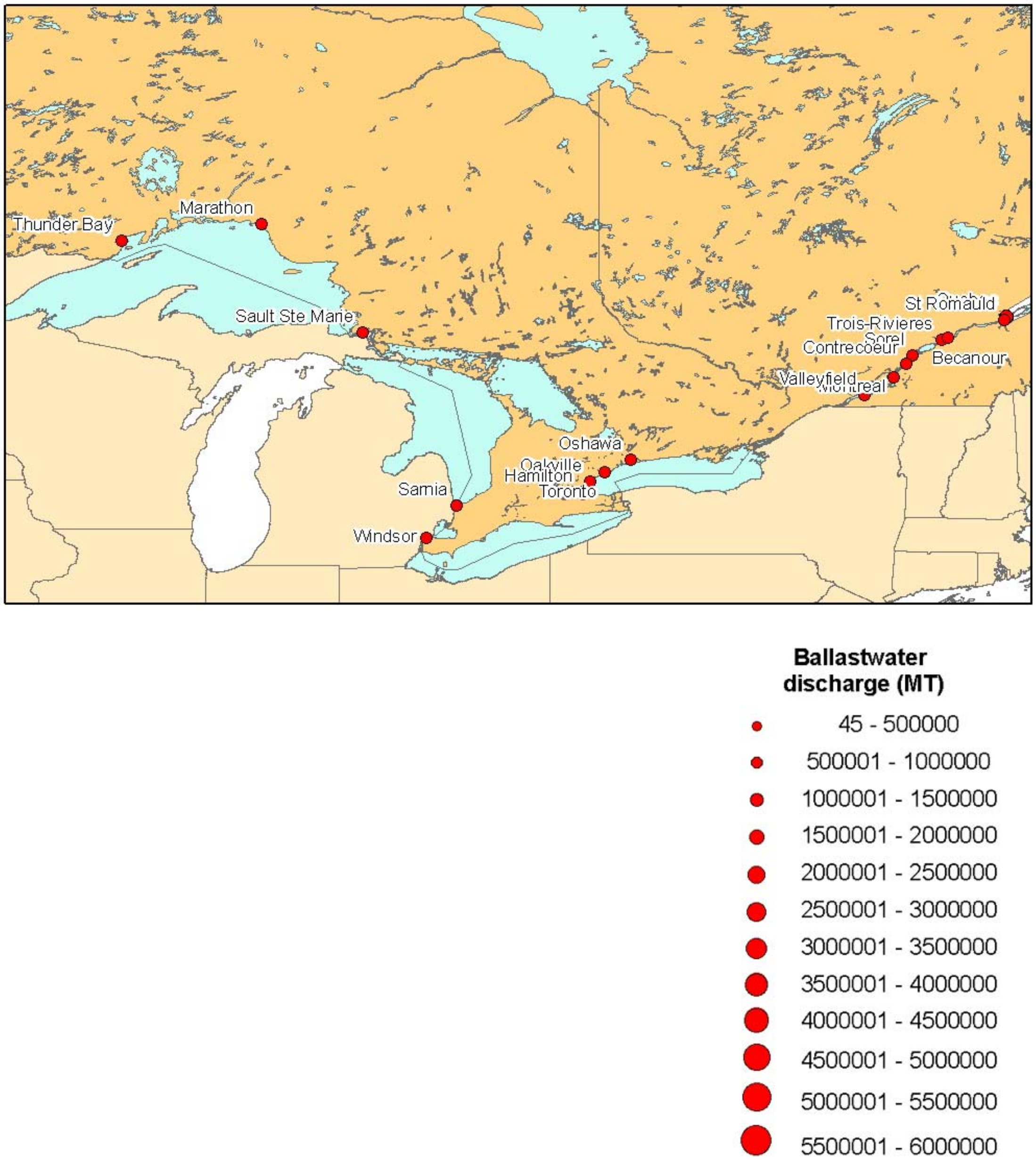

Figure 2: Total ballast water discharge volumes (in megatons, MT) in the Great Lakes-St. Lawrence, based on 2005 CBWDA data.

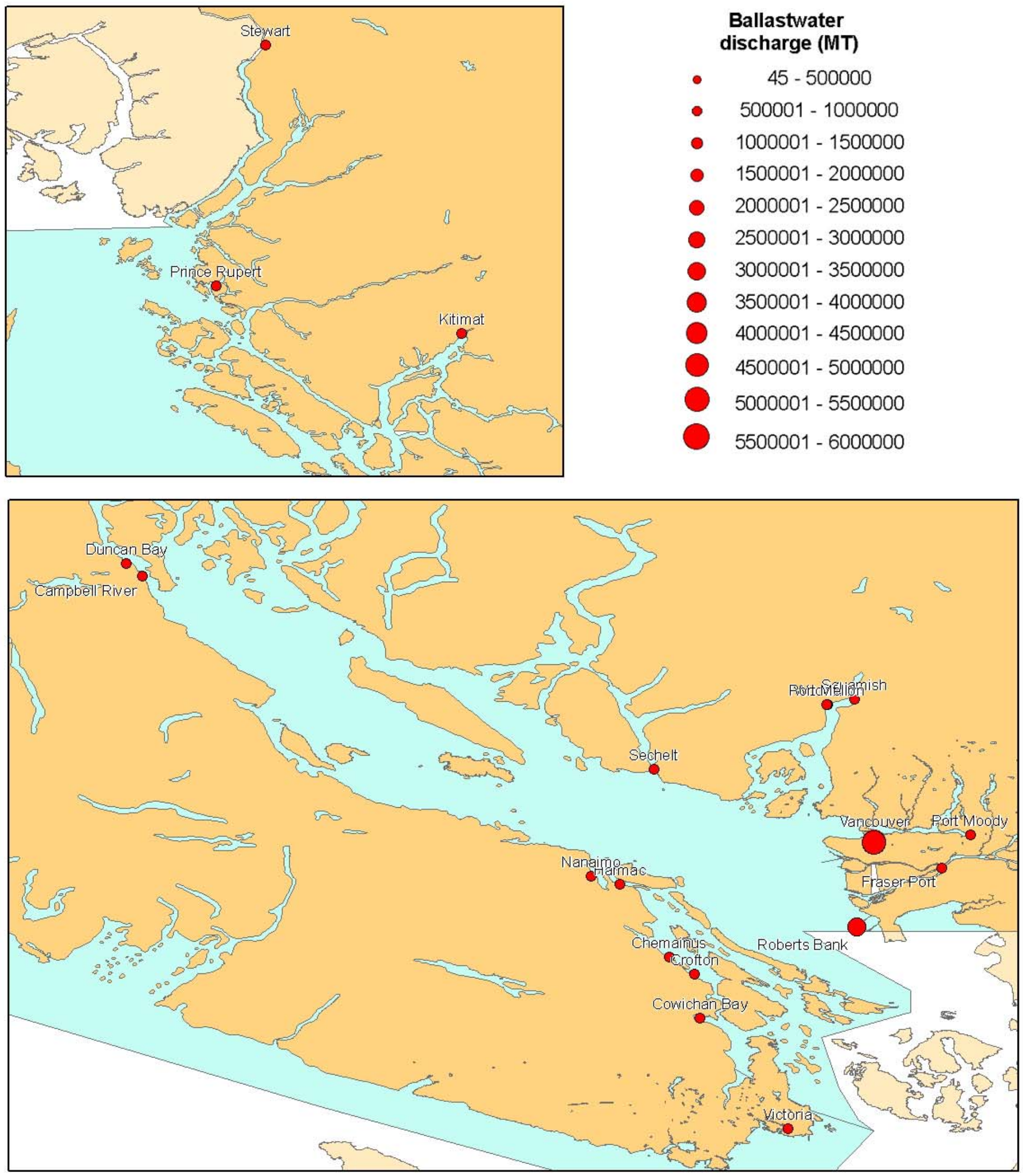

Figure 3: Total ballast water discharge volumes (in megatons, MT) on the Pacific Coast, based on 2005 CBWDA data.

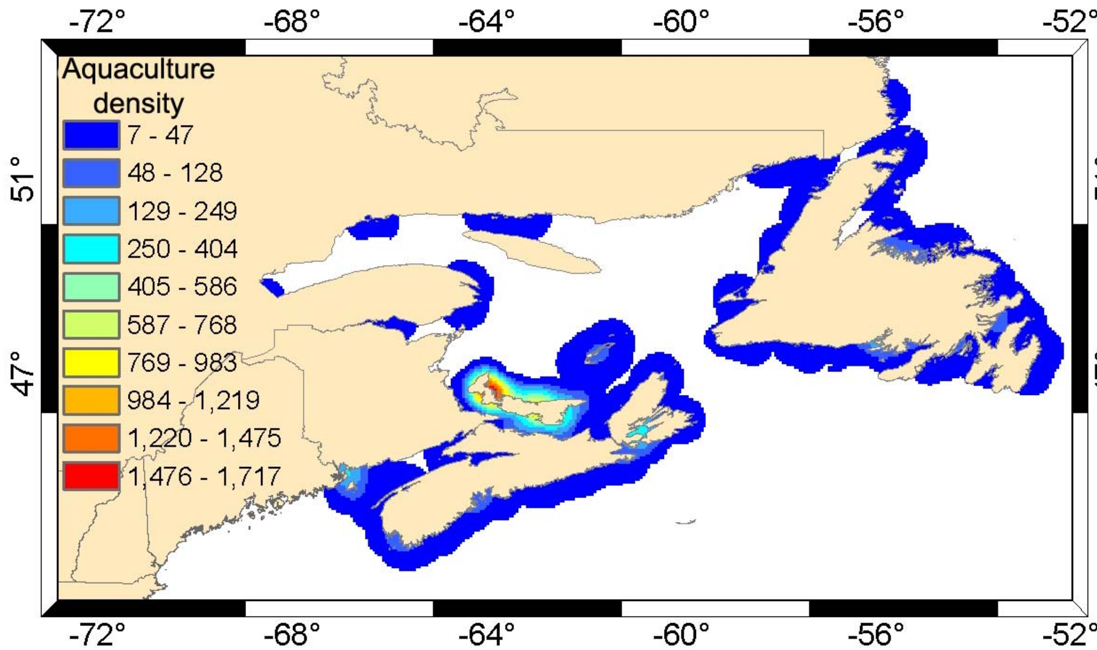

Figure 4: Relative density of aquaculture facilities around Atlantic Canada.

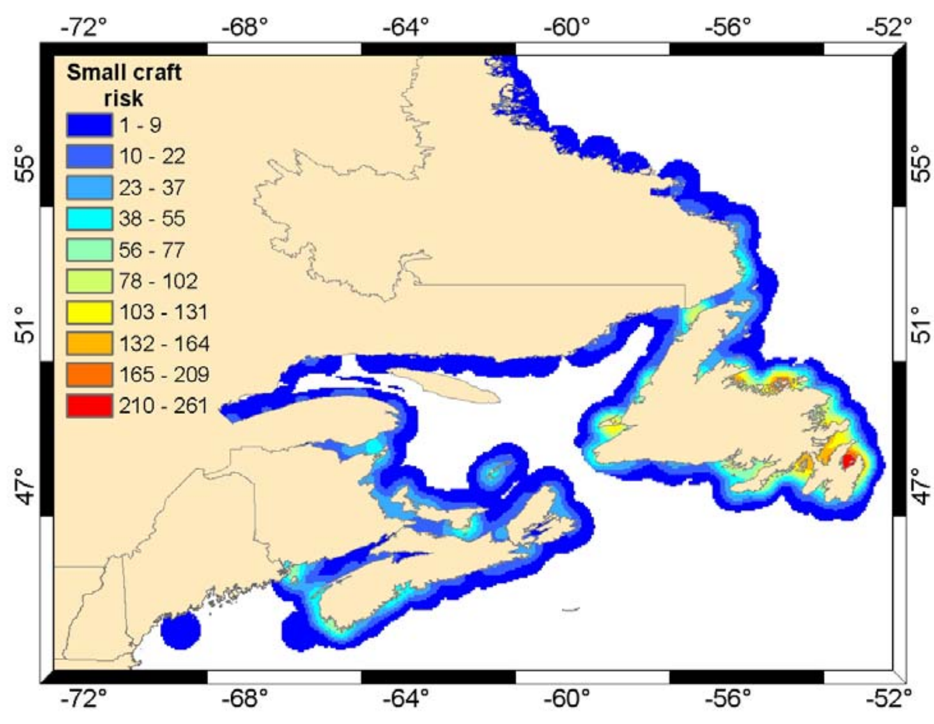

Figure 5: Relative density of small craft harbors around Atlantic Canada.

Other Potential Vectors: West Coast

A number of potential secondary dispersal vectors exist on the west coast including aquaculture-related transfers, recreational or small craft movements, and movements of commercial vessels including container ships, tankers, and fishing vessels. Most aquaculture in British Columbia (BC) is around the Strait of Georgia, notably Baynes Sound and Oekover Inlet (Figure 6). Higher than average densities also occur in the major inlets along the west coast of Vancouver Island and in Johnstone Strait (Figure 6). The highest density of small craft moorings is around the Strait of Georgia, extending through Johnstone Strait and into the Central Coast of BC (Figure 7). Additional point-source densities occur near Prince Rupert and Skidegate Inlet in the Queen Charlotte Islands (Figure 7). Most container ship activity in BC is related to international trade. These foreign vessels are entering Juan de Fuca Strait and heading to the ports of Vancouver or Delta to offload their cargo (Figure 8). Similar to container ships, most tanker traffic is into the port of Vancouver but additional tanker traffic in the north coast is destined to Prince Rupert and Kitimat, both ports recently scheduled for expansion (Figure 9). In BC, most fishing vessels are operating on inside waters. These include the Strait of Georgia, through Johnstone Strait, and along the mainland side of Queen Charlotte Sound and Hecate Strait right up to Dixon Entrance (adjacent to Prince Rupert) (Figure 10). Most of the tug and barge traffic in BC waters is within the Strait of Georgia (Figure 11). A similar level of traffic exists within Puget Sound, highlighting the interconnectedness of this inland sea. Additional tug and barge traffic exists within a relatively constrained band along the mainland coast extending from Vancouver in the south to Prince Rupert in the north (Figure 11).

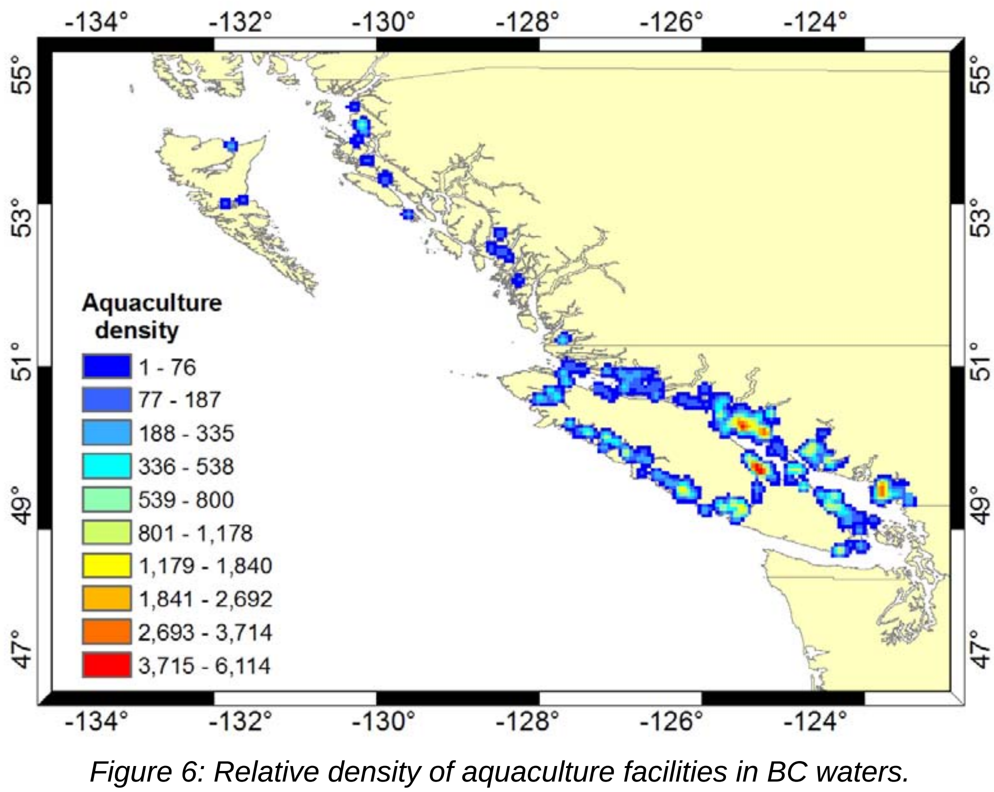

Figure 6: Relative density of aquaculture facilities in BC waters.

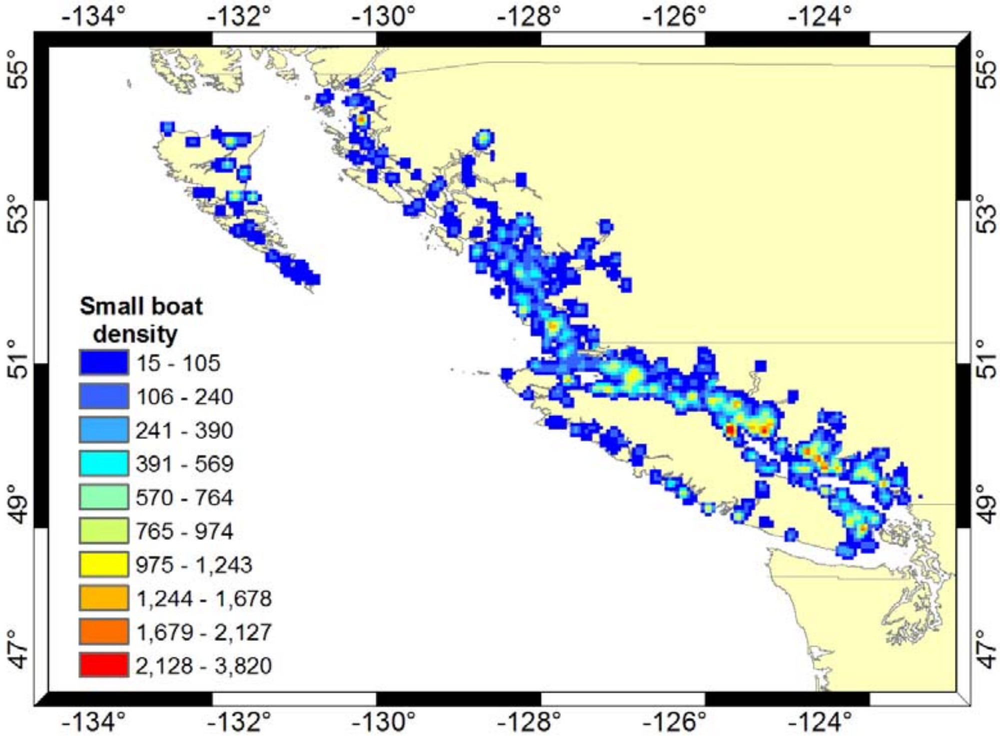

Figure 7: Relative density of small craft marinas, moorings and anchorages in BC waters.

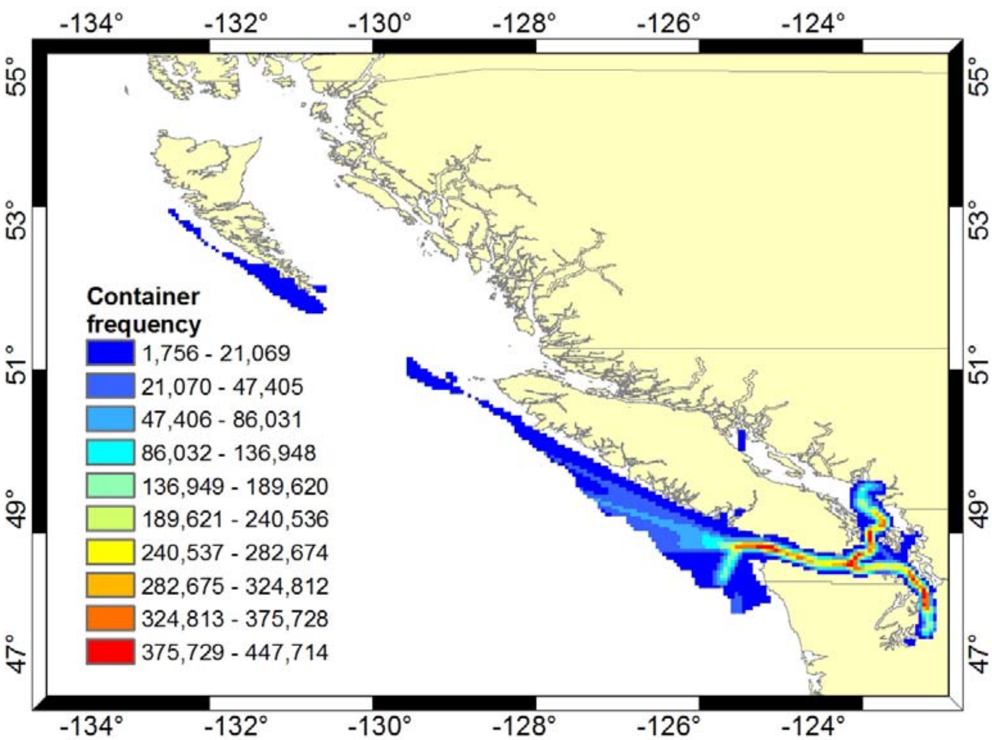

Figure 8: Relative density of container ship activity in BC waters.

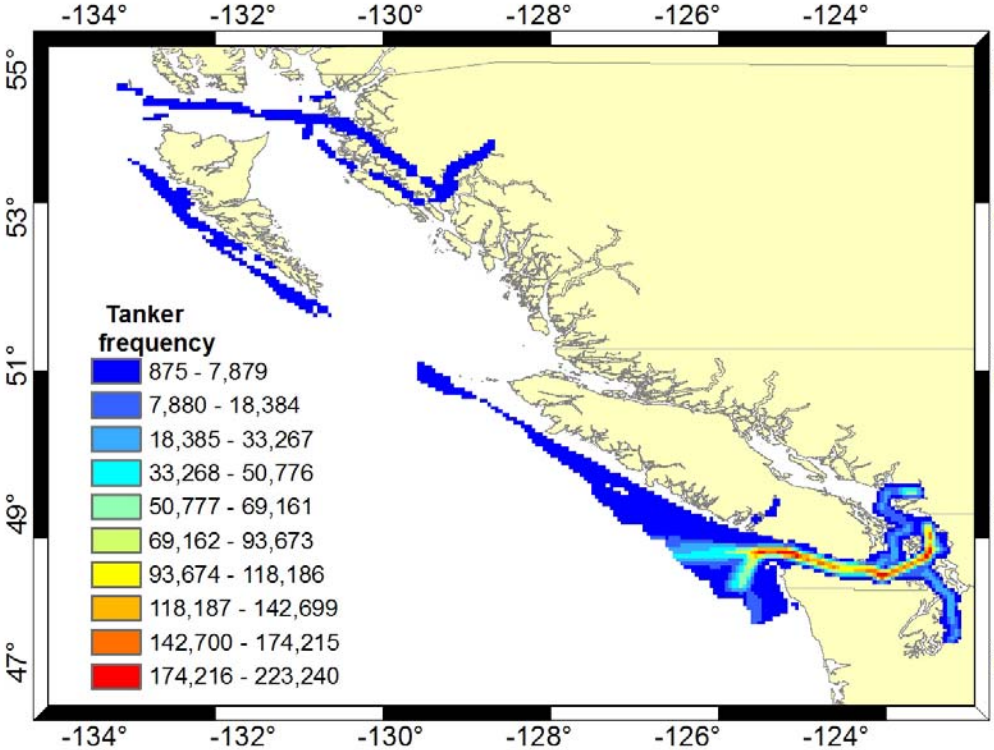

Figure 9: Relative density of tanker ship activity in BC waters.

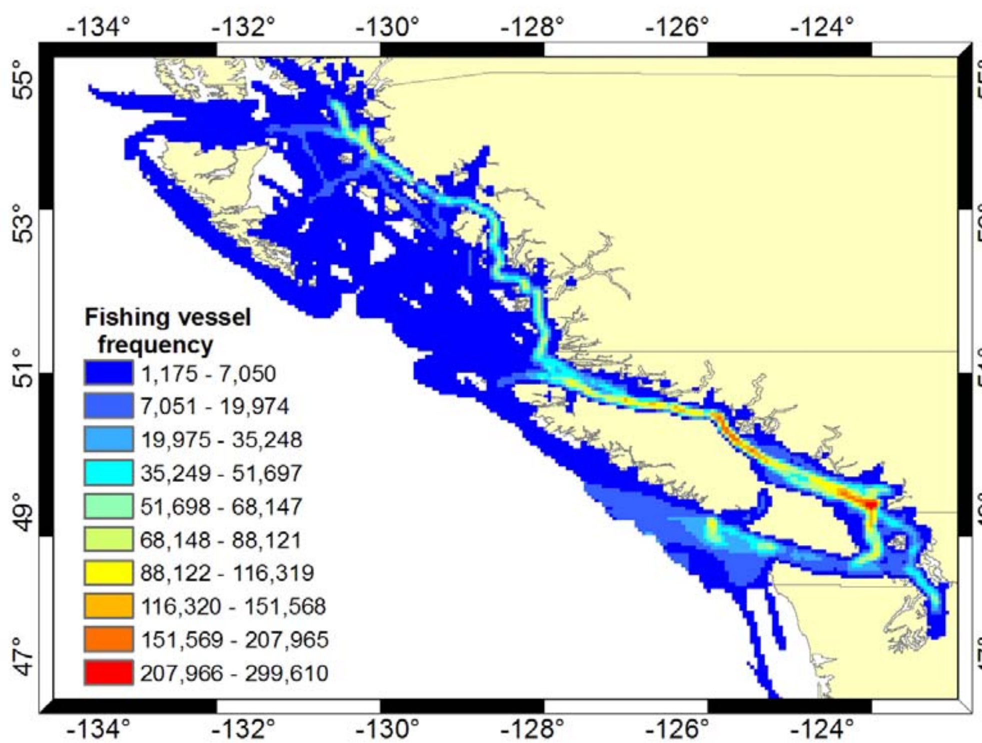

Figure 10: Relative density of fishing vessel activity in BC waters.

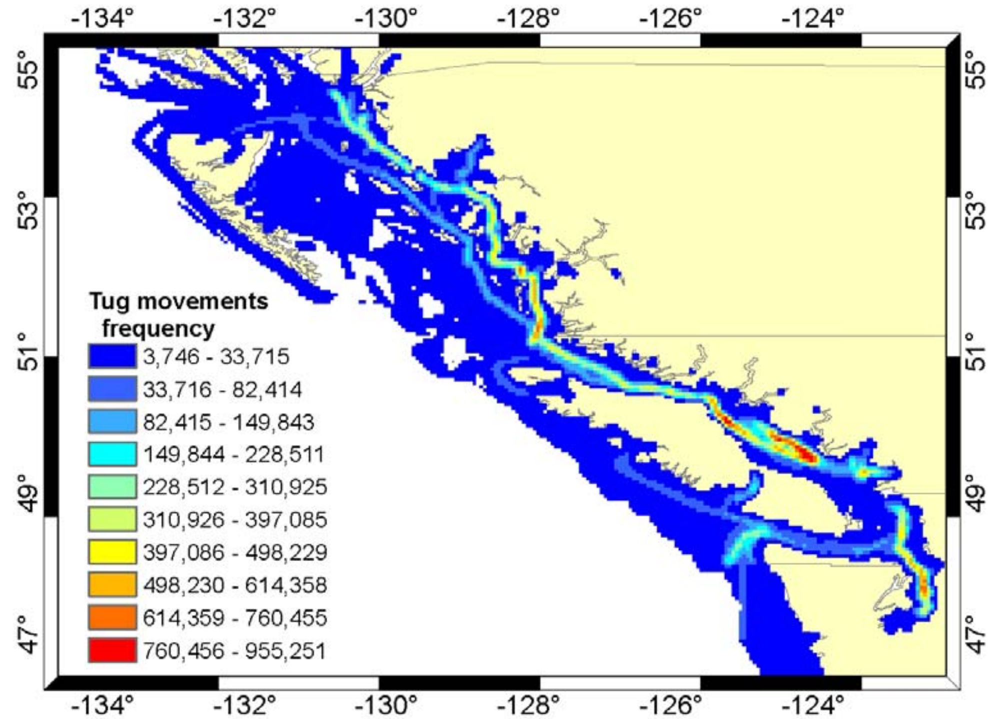

Figure 11: Relative density of tug/barge activity in BC waters.

Chinese Mitten Crab (*Eriocheir sinensis*) Risk Assessment

Background and biology

The Chinese mitten crab is a catadromous crustacean whose native range extends from Hong Kong to North Korea (22°N – 41°N). This decapod crab with a carapace width up to 10cm possesses distinctive fur-like hair on its claws. In Poland, Normant et al. (2007) reported a number of epibionts living in the mittens (hairy claws). It reproduces in the brackish marine sections of estuaries, where the adults die after larval release. The pelagic larvae require salinities of at least 15‰ for successful development and settle after a larval duration of ~90days (Anger, 1991). No research has been done on larval dynamics of this species but in the North Sea where Chinese mitten crabs have spread widely, the coastal waters are full salinity. Juvenile crabs then undertake an upstream, riverine migration that can extend several hundred kilometers and occur over several years. In spring juvenile crabs (Herborg et al., 2003) once they reach sexual maturity after 1 – 3 years in China (Jin et al., 2002) or 2 – 5 years in Europe (Schubert, 1938) they migrate back to an estuary "en masse" in late summer, where they complete their life cycle by reproducing and dieing (Peters, 1938). During these extensive migrations, mitten crabs frequently have been observed walking over dry land or around obstacles. There is an ongoing taxonomic debate on the genus *Eriocheir*, especially with respect to different mitten crab "groups" along the Chinese coastline (Chu et al., 2003; Lu et al., 2000; Tang et al., 2003). This could have implications if purported "groups" have different environmental tolerances, thereby affecting their potential distribution.

In systems they have invaded, a number of adverse environmental consequences have been attributed to mitten crabs. For example, commercial trawl-fishermen have been forced to abandon certain areas in San Francisco Bay, California, USA and in Dutch estuaries when mitten crab populations were large (Ingle, 1986; Veldhuizen and Stanish, 1999). The species also causes riverbank erosion due to extensive burrowing activity (up to 30 burrows per m^2) in tidal sections of some rivers (Dutton and Conroy, 1998; Peters, 1933). Mitten crabs prey largely on surface-dwelling invertebrates (Rudnick and Resh, 2005), possibly competing with native invertebrate and fish species. While mitten crabs have demonstrated a range of negative impacts in their invaded range, this species supports a $1.25 billion per annum aquaculture industry in China supplying local and international markets with live animals (Hymanson et al., 1999).

Known distribution

Eriocheir sinensis has a rapidly expanding global distribution. It was first reported in Europe in 1912 in northern Germany (Peters, 1933). By the 1930s it had spread inland via several major rivers including the Elbe, Weser, Odra and Rhine, in addition to many smaller rivers and canals. The arrival of mitten crabs in the Elbe followed the introduction of cargo vessels carrying ballast water. Additionally, large specimens were found in the sea chests during ship breaking of old cargo vessels (Peters, 1933). During the 1930s the population reached very high levels, an annual catch of 242 metric tons was recorded for the River Elbe alone (Panning, 1938). At the same time, coastal spread occurred from the North Sea to the Baltic Sea as well as into the English Channel. Further dispersal in Europe occurred in the 1950s from the French Atlantic coast to the Mediterranean Sea through the Gironde River and connected canals (summarized in Herborg et al., 2003; Herborg et al., 2005). Recently this crab also has spread along the Atlantic Coast of Spain and Portugal (Cabral and Costa, 1999). Most European introductions followed a similar pattern, starting off with an extended lag-phase, with only a few crabs reported over a period of several years (up to 22 years in the Thames). After this lag-phase a sharp increase in population densities and geographical spread along the coastline and upstream frequently was observed (Herborg et al., 2003; Herborg et al., 2005).

In North America, the first reports were of single individuals in the Laurentian Great Lakes (Nepszy and Leach, 1973) with a recent increase in the frequency of these observations between 2004 – 2006 (Veilleux and de Lafontaine, 2007). The only established population in North America exists in San Francisco Bay, California (USA), where over 700,000 individuals were caught only seven years following the initial introduction (Rudnick et al., 2003), but population numbers have recently dropped. Although mitten crab was reported from Portland, Oregon, this was the Japanese mitten crab (*E. japonicus*) rather than the Chinese mitten crab. Genetic analysis of the San Francisco Bay population identified Europe as the most likely source population, making intentional release for the establishment of a fishery a likely pathway of introduction (Hanfling et al., 2002).

Potential distribution in Canada

Based on GARP model predictions using the Asian distribution of Chinese mitten crab the highest environmental suitability exists around southwestern Nova Scotia on the Atlantic coast (Figure 12). Moderate suitability exists around much of the rest of Nova Scotia and lower suitability around Prince Edward Island, the mouth of the St. Lawrence River and the Avalon Peninsula of Newfoundland (Figure 12). Based on GARP model predictions using the European distribution of Chinese mitten crab the highest environmental suitability exists throughout much of Nova Scotia and Prince Edward Island with lower environmental suitability around New Brunswick, and parts of Quebec and Newfoundland (Figure 13). On the Pacific coast the GARP model prediction using the Asian distribution of Chinese mitten crab showed the highest environmental suitability

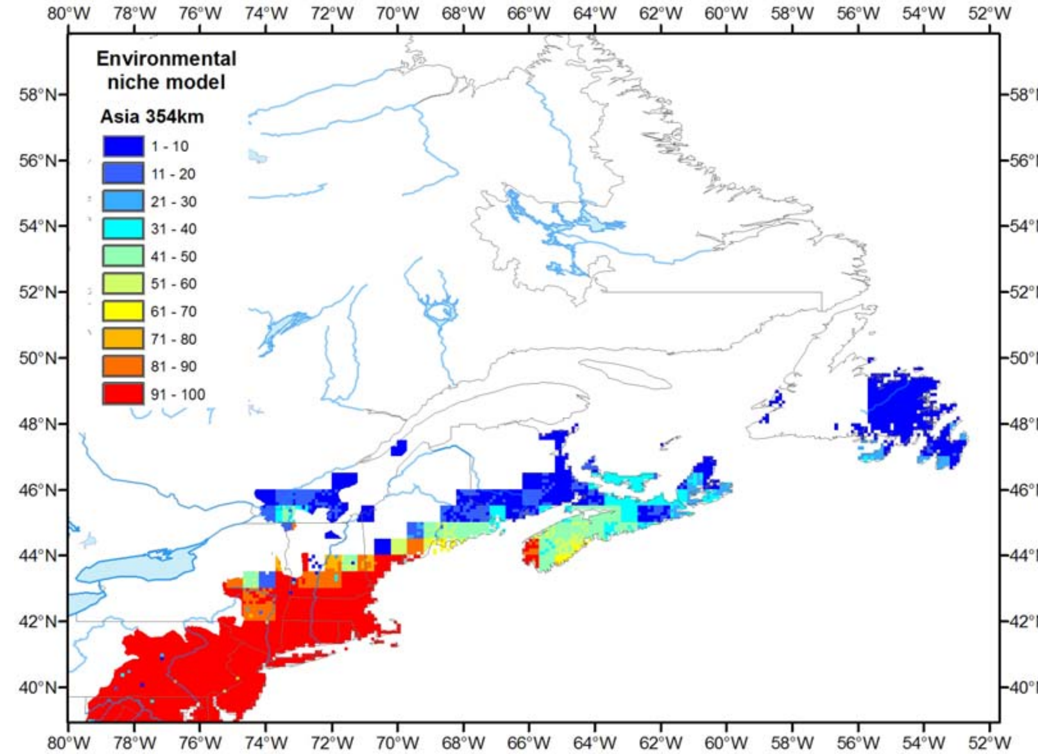

Figure 12: Potential distribution of Chinese mitten crab on the Atlantic coast based on GARP model predictions using the Asian distribution of Chinese mitten crab.

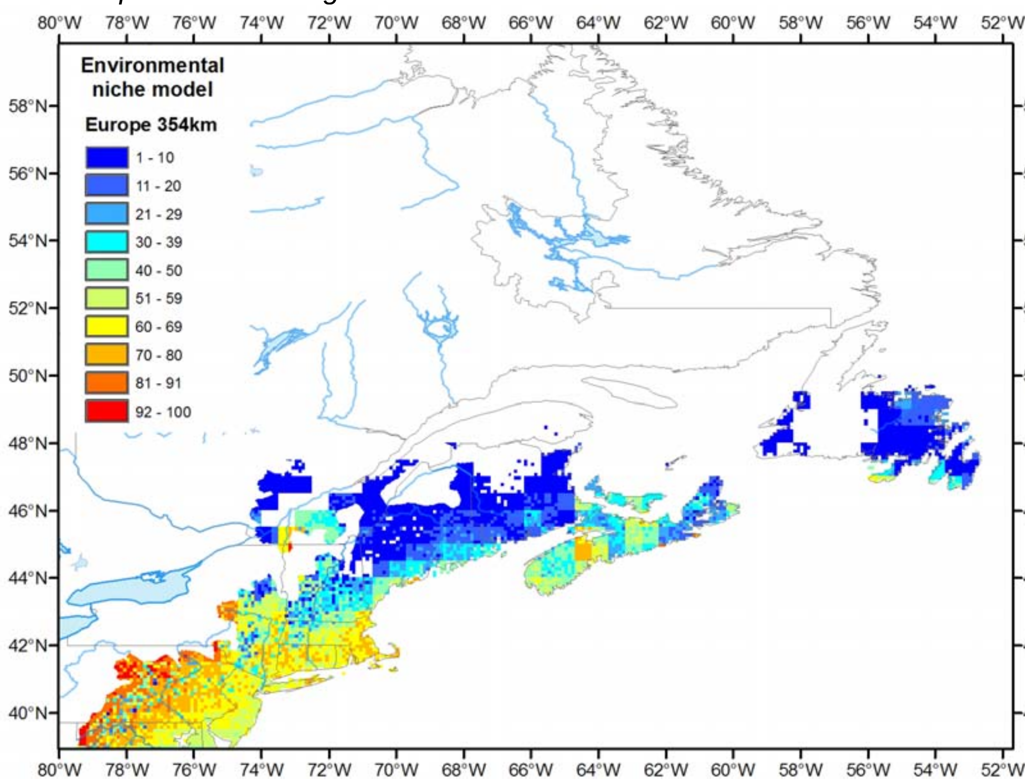

Figure 13: Potential distribution of Chinese mitten crab on the Atlantic coast based on GARP model predictions using the European distribution of Chinese mitten crab.

around the southern Strait of Georgia (including both the lower mainland side and the southeastern coast of Vancouver Island) and Puget Sound, WA (USA) (Figure 14). Applying the GARP model based on the European distribution of Chinese mitten crab showed high environmental suitability around all of Vancouver Island, including the Strait of Georgia and Johnstone Strait and around Puget Sound, WA (USA) (Figure 15). Additional areas of high environmental suitability exist around the North Coast of British Columbia around the Skeena and Nass Rivers (Figure 15).

Survey results

The survey of crab and aquatic invasive species experts identified several potentially important vectors for the introduction of Chinese mitten crabs. In this discussion the category “other” is not included as the respondents did not always indicate how they defined it (and few respondents used this category). Overall, ballast water was perceived by the surveyed experts to be the single most important vector for the initial establishment of Chinese mitten crabs (70% of respondents suggested that this vector was of high or very high importance for initial establishment), followed by intentional release (39%) and aquaculture (29%) (Figure 16). This was followed by directed adult migration, fisheries and artificial waterways, with about one quarter of respondents believing that these factors are of at least high importance to Chinese mitten crab initial establishment. Other factors were largely (over 65% of all respondents) considered to be of low or very low importance. Almost one third (mean 29%) of respondents considered that there was a moderate level of uncertainty with respect to the classifications of importance they provided for the different vectors for initial establishment. Overall, the uncertainty of the experts surveyed with respect to each of the potential vectors was high, with 30-52% of experts surveyed having either a high or very high uncertainty for the importance they attributed to 8 of 9 of the vectors considered. The only exception was ballast water, for which the experts were more sure (55% with a very low or low uncertainty).

Secondary spread was viewed to be largely related to dispersal via natural processes such that 78 and 63% of respondents suggesting that migration by adults and larval drift, respectively, are of high or very high importance for secondary spread (Figure 17). Secondary spread via artificial waterways and ballast water also were regarded as important with 68 and 47% of respondents believing that these vectors are at least of high importance to this end. All other factors were largely considered (as indicated by over 56% of all respondents) to be of low or very low importance to secondary spread of Chinese mitten crabs, with the exception of intentional release, for which only 37% of respondents believe so. About one quarter (mean 25%) of respondents considered that there was a moderate level of uncertainty with respect to the classifications of importance they provided for the different vectors for secondary spread. The uncertainty of the experts surveyed with respect to each of the potential vectors varied such that there was fairly low uncertainty (low or very low) for only two vectors: migration by adults (67%) and canals and artificial waterways (58%). High or very high uncertainty (as identified by 27-53% of all respondents) was recorded for the other variables.

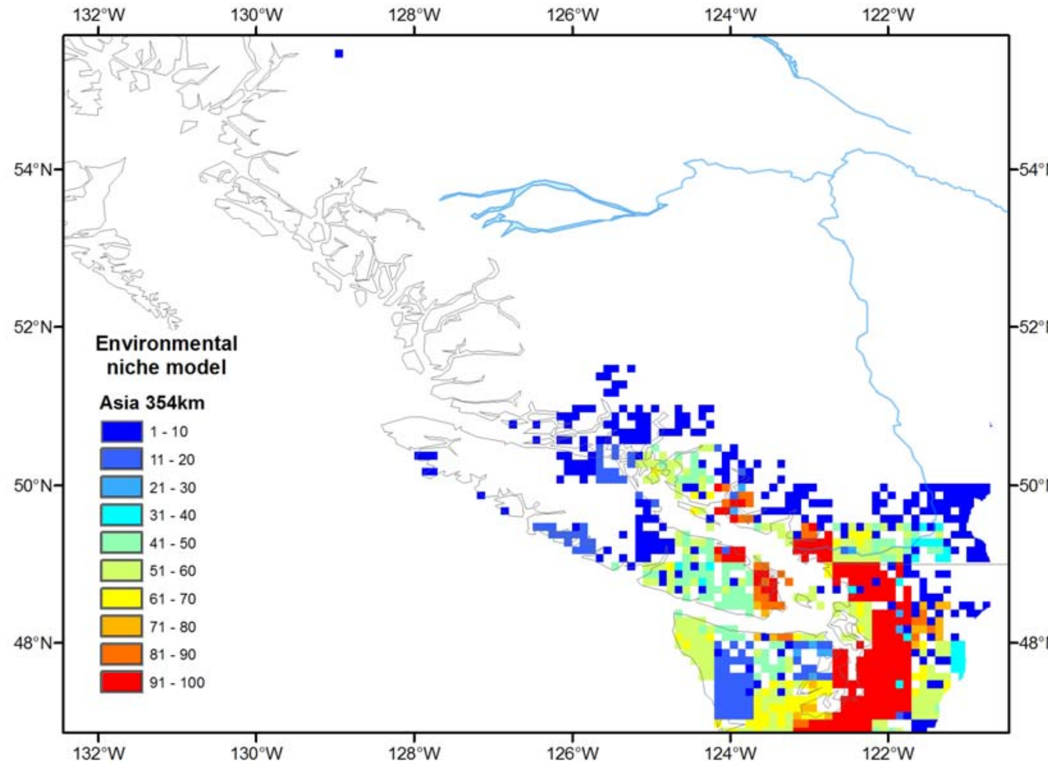

Figure 14: Potential distribution of Chinese mitten crab on the Pacific coast based on GARP model predictions using the Asian distribution of Chinese mitten crab.

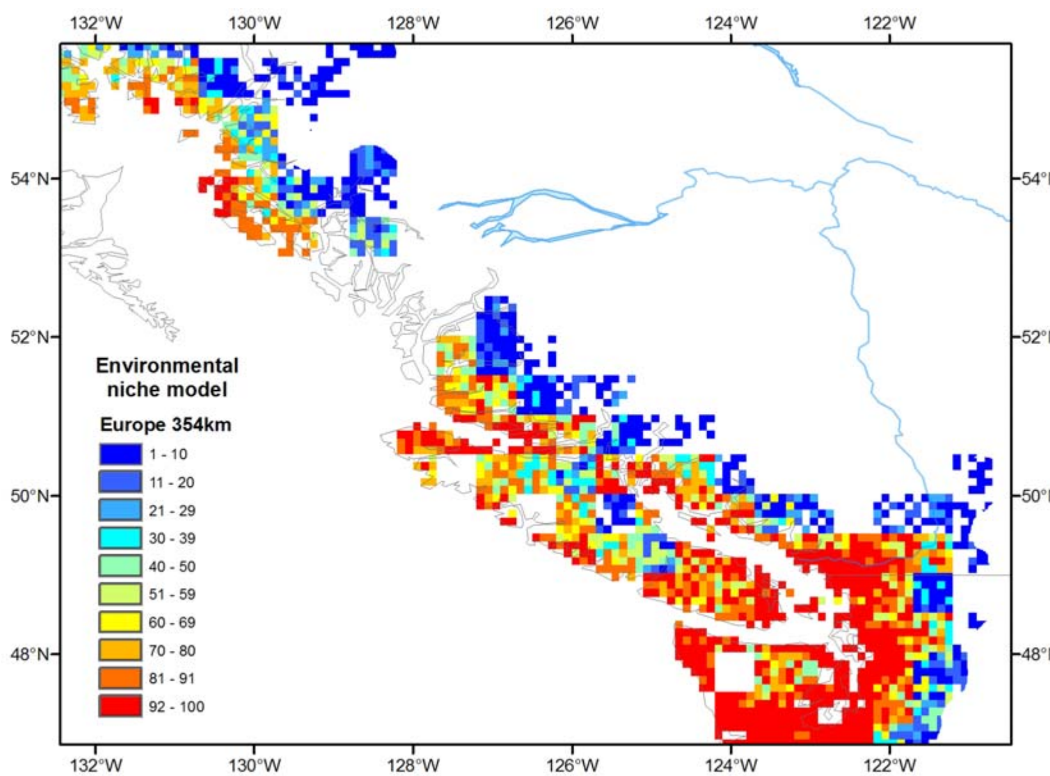

Figure 15: Potential distribution of Chinese mitten crab on the Pacific coast based on GARP model predictions using the European distribution of Chinese mitten crab.

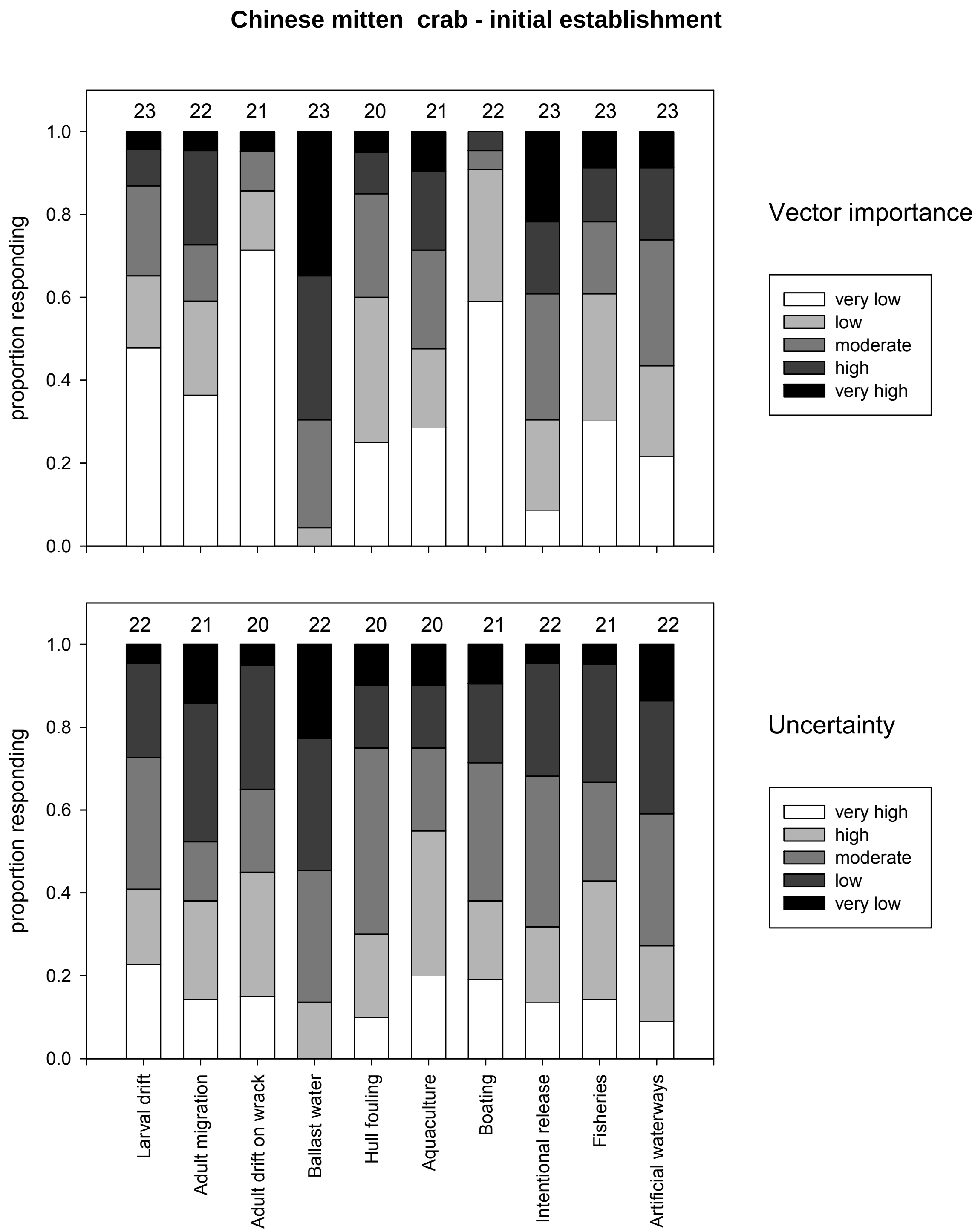

Figure 16: Relative vector importance and uncertainty for the initial establishment of Chinese mitten crab as determined by experts via an online survey.

Chinese mitten crab - secondary spread

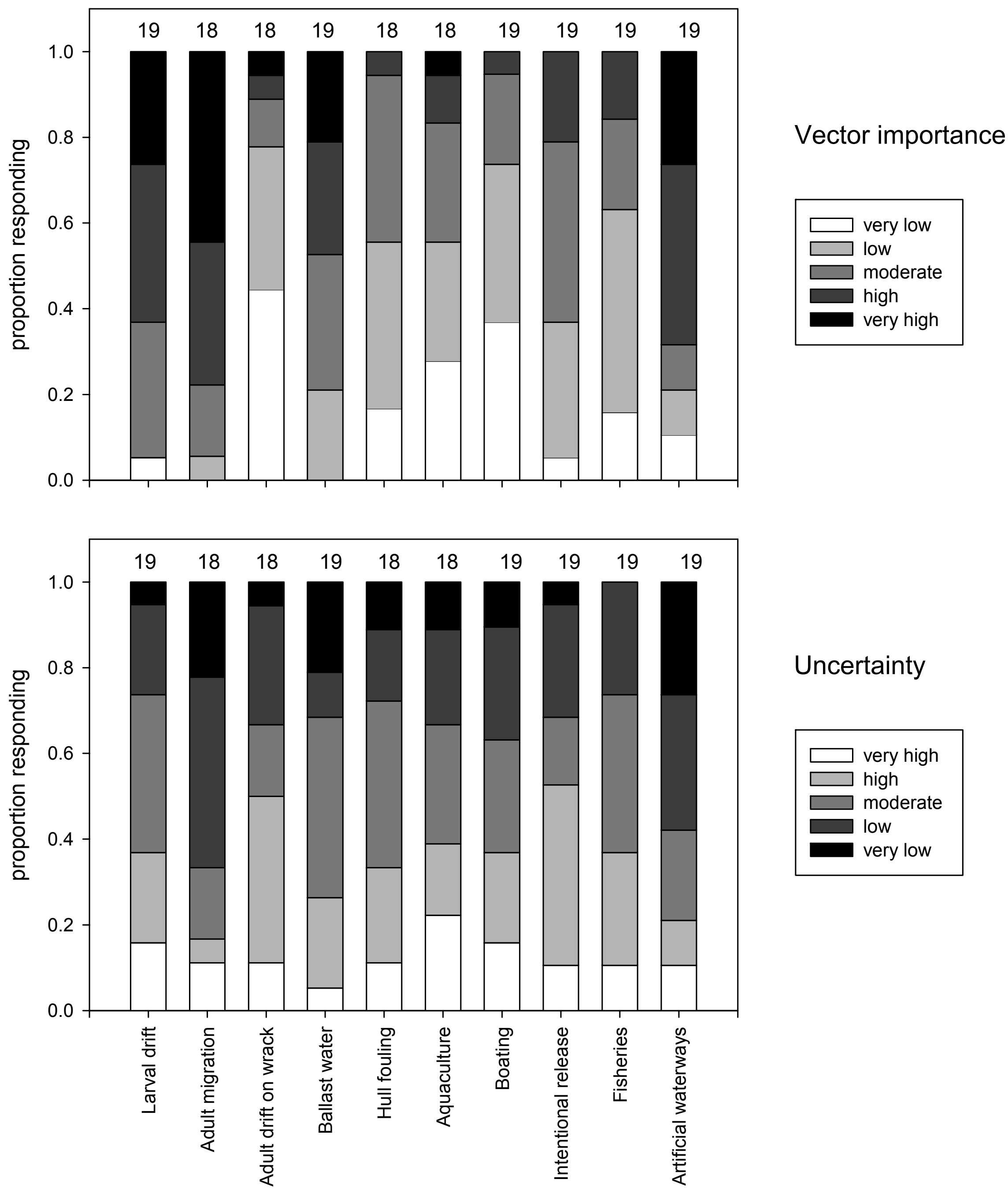

Figure 17: Relative vector importance and uncertainty for the secondary spread of Chinese mitten crab as determined by experts via an online survey.

These results are largely consistent with the available literature on the subject. The initial dispersal of Chinese mitten crab is usually linked to dispersal by commercial shipping (ballast and fouling/sea chests) and the intentional release of crabs to establish new food resources (Cohen and Carlton, 1995; Hanfling et al., 2002). Although aquaculture was identified as an important vector for primary introductions, it is doubtful whether the application of Introductions and Transfers regulations in North America would allow the introduction of Chinese mitten crab at this time. Most experts agreed that both directed movement and larval drift are mechanisms of high or very high importance to secondary spread. This is logical given this species' demonstrated propensity to undertake great migrations (see Herborg et al., 2007a) and the great abundance of eggs that they may produce (up to 1 million eggs at a time) and the extended larval lifespan (>60 days). Similarly, the belief by most respondents that canals and artificial waterways are important to the secondary spread of this species is logical given the aforementioned propensity of this species to undertake great migrations. Ballast water was again indicated to be important for secondary spread and this is supported by the observation of larvae in ballast samples and for the later larval stages to be able to develop over a range of salinities. Overall, the uncertainty associated with these mechanisms reflected the perceived importance of each such that those identified as being of most important were typically also identified as having the lowest uncertainty associated with them.

Impact likelihood estimates were provided by 16 to 20 respondents for the individual questions. Only two respondents provided additional impacts in the 'other' category. The impact of mitten crabs on flood protection / river erosion was identified as being very high negative (Figure 18). This is supported by the well documented history of mitten crabs burrowing into river banks (Dutton and Conroy, 1998), nevertheless it should be noted that the burrowing activity mainly occurs in rivers and estuaries with tidal influence. Therefore, while the river bank erosion can be significant in some areas with up to 30 burrows per m^2, its impact will be limited to tidally influenced areas. Mean impacts were high negative for freshwater and estuarine biodiversity (Figure 18). Mitten crab populations can reach high abundance in the estuaries and rivers during their juvenile phase, feeding on benthic invertebrates. The impact on shellfish fishery was deemed moderate, which agrees with reports of mitten crabs eating thin shelled bivalves in rivers, nevertheless since the adults are not feeding during their marine phase the impact on marine shellfish fisheries will be very limited (if they exist at all). Each of finfish fishery, shellfish aquaculture and fisheries were predicted to be low negatively impacted, which was an expected estimate due to the lack of feeding in the marine adult phase of the species. Overall the experts' estimates of impact were similar to the limited descriptions on impacts in the literature which provides support for the use of expert surveys on lesser studied species.

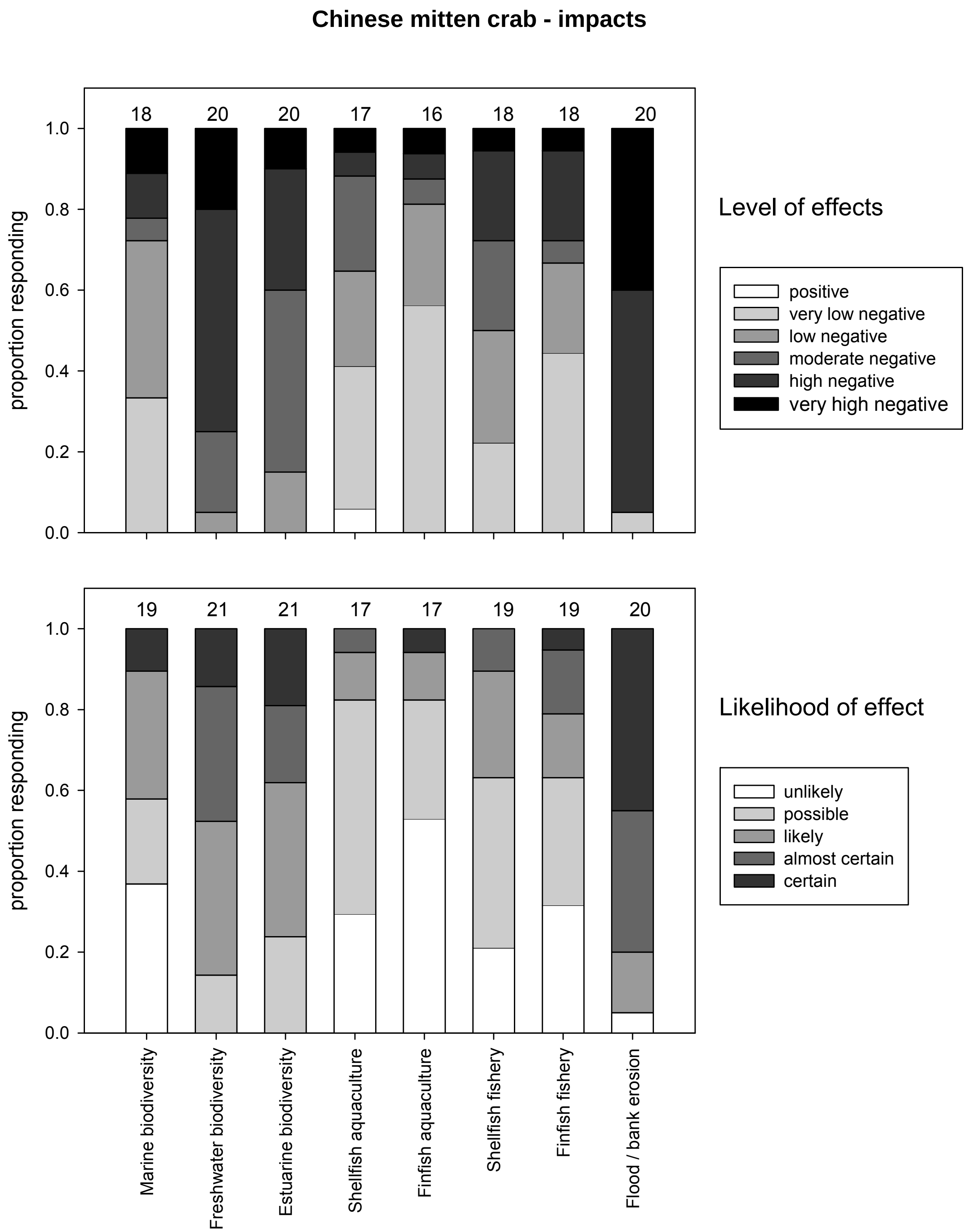

Figure 18: Potential impacts of Chinese mitten crab introductions as determined by experts via an online survey that identified the level of impact and its likelihood.

Risk Assessment Part I – Aquatic Organism Ecological and Genetic Risk Assessment Process for Chinese Mitten Crab

Step 1: Determining the Probability of Establishment

(1) Estimate of probability of the organism successfully colonizing and maintaining a population if introduced.

The primary vector proposed for the introduction of Chinese mitten crab worldwide is commercial shipping, primarily larval transport in ballast water. On the west coast, Vancouver is the main recipient port for ballast water. These ballast water discharges represent both ships originating in the mitten crab's native range, Asia, and ships originating from where mitten crab have been introduced on the west coast of North America, San Francisco Bay (Figure 3). Both sources pose a risk of introduction to Canadian ecosystems. In the Great Lakes area, the three main ports receiving ballast water; Quebec, Montreal, and Sorel, are located in the lower St Lawrence, in areas where released mitten crab larvae could mature and reach brackish waters for reproduction (Figure 2). On the east coast the potential for new introductions to sites with very high levels of ballast water discharge such as Point Tupper, Come-by-Chance and Sept-Iles (Figures 1) have an increased probability of mitten crab arrivals. In addition to potential dispersal vectors, there are locations of high environmental suitability on both coasts (Figures 12 to 15) suggesting that if Chinese mitten crab were introduced they could find suitable habitat to survive. Due to the catadromous life history of this species it is unclear how natural dispersal from the initial introduction site via larval drift contributes to the spread of this species once established.

Given that mitten crab has arrived and survived previous introductions in Atlantic Canada we assigned these probabilities very high. There are no known established mitten crab populations in Atlantic Canada suggesting the probability of reproduction is lower: we classified it as moderate. In Pacific Canadian waters there are no known arrivals of this crab species. Due to potential dispersal vectors, especially commercial shipping from San Francisco Bay and Asia, in addition to potentially suitable habitat, we classified both the probability of arrival and survival as high. The probability of reproduction is moderate. Given that the probability of reproduction is the apparent limiting step in the invasion process on both the Atlantic and Pacific coasts we assigned an overall probability of establishment of moderate for both coasts.

(2) If the organism escapes from the area of introduction, estimate the probability of its spreading.

The catadromous life history of this crab requires considerable time spent in freshwater relative to the marine environment. In Atlantic Canada there are a large number of potentially suitable environments owing to the large number of drainages that connect to the St. Lawrence River/Gulf of St. Lawrence drainage. Further, spread also is a function of available dispersal vectors and the high volume of commercial shipping activities in this area could spread Chinese mitten crab if introduced in Atlantic Canada. Thus, the probability of spread is very high. In Pacific Canada there also is a significant amount of suitable habitat and commercial shipping primarily in the Strait of Georgia, suggesting the probability of spread is high. However, on both coasts it is unclear how the relative contributions of adult vs. larval dispersal might contribute to the spread of this species. Thus, the uncertainty about spread on both coasts is considered high.

(3) Final Rating: Chinese mitten crab.

	Atlantic Coast		Pacific Coast	
Element	Rank	Uncertainty	Rank	Uncertainty
Arrival	Very High	Very Low	High	Low
Survival	Very High	Very Low	High	Low
Reproduction	Moderate	High	Moderate	High
Overall Establishment	**Moderate**	**High**	**Moderate**	**High**
Spread	Very High	High	High	High

Step 2: Determining the Consequences of Establishment of an Aquatic Organism

(1) Impacts on native ecosystems both locally and within each region.

Based on the results of its introduction throughout the world (Veilleux and de Lafontaine, 2007) and input from our expert survey, there is little doubt that Chinese mitten crab could have significant negative impacts if introduced, including impacts on habitat structure and potentially foodweb and trophic structure of aquatic ecosystems by inducing changes in plant, invertebrate and possibly fish communities. The survey identified the most severe impact of a mitten crab invasion on flood protection/riverbank erosion (Figure 18), which is in agreement with the literature that documents extensive burrowing by this species. Thus, there could be a very high impact on flood protection/river bank erosion, a specific sub-category of habitat impacts. Other examples of habitat impacts include uprooting of submerged macrophytes. The survey also identified high impacts on freshwater and estuarine biodiversity, likely through competition with native species, which also could affect SARA or COSEWIC listed species, including a variety of freshwater mussels and could affect freshwater fish via predation on their eggs. For example, in Atlantic Canada Chinese mitten crab could be potential predators on yellow lampmussel (*Lampsilis cariosa*) and be a potential competitor with molluscivores such as copper or river redhorse (*Moxostoma hubbsi* and *M. carinatum*, respectively). Other impacts were moderate to low with the exception of genetic impacts that were deemed very low as no other *Eriocheir* species exist in Canada. Although the expert survey ranked the impact on shellfish fisheries as moderate the literature suggests that during this part of their life cycle Chinese mitten crabs are not feeding (and in fact are contributing extra biomass to the marine environment). Thus, we classified the impact on shellfish fisheries as low since most (if not all) shellfish fisheries in Canada occur in marine waters. Impacts on wild fisheries are largely due to egg predation, including predation on commercially important species such as noted for San Francisco Bay.

(2) Final Rating: Chinese mitten crab.

	Survey/Literature Results		Peer-review Results	
Element	Magnitude	Likelihood	Magnitude	Uncertainty
Biodiversity Consequences				
Marine	Low	Possible	Very Low	Very High
Freshwater	High	Almost Certain	High	Low
Estuarine	High	Likely	High	Moderate
Shellfish Aquaculture	Low	Possible	Low	Very High
Finfish Aquaculture	Low	Unlikely	N/A	N/A
Shellfish Fishery	Low (Moderate)	Possible	Low	Moderate
Finfish Fishery	Low	Possible	Moderate	Very High
Wildlife/Human Health Consequences	Low	Likely	Moderate	Very High
Habitat Consequences	Moderate	Likely	Moderate	Very Low
Flood Protection /River Bank	Very High	Likely	Very High	Very Low
Genetic Consequences	Very Low	Unlikely	Very Low	Very Low

Step 3: Summary of the Aquatic Organism Overall Risk Potential for Chinese mitten crab.

	Atlantic Canada		Pacific Canada	
Element	Rating	Uncertainty	Rating	Uncertainty
Biodiversity Consequences				
Marine	Low	Very High	Low	Very High
Freshwater	Moderate	High	Moderate	High
Estuarine	Moderate	High	Moderate	High
Shellfish Aquaculture	Moderate	Very High	Moderate	Very High
Finfish Aquaculture	N/A	N/A	N/A	N/A
Shellfish Fishery	Moderate	High	Moderate	High
Finfish Fishery	Moderate	Very High	Moderate	Very High
Wildlife/Human Health Consequences	Moderate	Very High	Moderate	Very High
Habitat Consequences	Moderate	High	Moderate	High
Flood Protection /River Bank	High	High	High	High
Genetic Consequences	Low	High	Low	High

Risk Assessment Part II – Pathogen, Parasite or Fellow Traveler Risk Assessment Process for Chinese Mitten Crab

Step 1: Determining the Probability of Establishment

(1) Estimate the probability that a pathogen, parasite or fellow traveler may be introduced along with the potential invasive species. Note that several pathways may exist through which pathogens or accompanying species can enter fish habitat. Each must be evaluated.

Little is known about the parasites, pathogens, and fellow travelers of Chinese mitten crab (Veilleux and de Lafontaine, 2007). However, the mitten crab is the first intermediate host for the oriental lung fluke, *Paragonimus westermani*, which requires a second intermediate host, a snail in the family Thiaridae to complete its life cycle and reach its final host, mammals, including humans who consume under-cooked mitten crab (Cohen, 2003). The second intermediate host is a warm-water species not currently found in northern Europe or North America. Thus, this fluke does not currently have the ability to complete its life cycle (and infect humans). However, there are multiple potential vectors that could deliver Chinese mitten crab and their associated hitchhikers to Canadian ecosystems. The importation of live mitten crab for human consumption likely poses the greatest risk for arrival of the lung fluke as it appears larvae can not carry the fluke. In addition to the lung fluke, the fur-like claws of the mitten crab are known to entrain a variety of fellow travelers. Again, due to the potential release via the live food market, the probability of arrival of a hitchhiker should be considered high. Whether or not these organisms will be able to survive or reproduce is less clear but since none have been reported to our knowledge we consider these probabilities to be moderate. Uncertainty for all aspects of the probability of establishment is very high as there is little published information on this topic.

(2) Estimate the probability that the pathogen, parasite or fellow traveler will encounter susceptible organisms or suitable habitat.

The lung fluke has a very complex life history and requires an intermediate host that is not reported from Canada or other northern countries. However, it is unknown how species specific the variety of invertebrate epibionts are and whether or not they could encounter susceptible organisms if introduced. Thus, the probability of spread is considered to be moderate. There is no evidence to suggest that pathogens, parasites, or fellow travelers would spread more (or less) on either coast so we used the same probabilities for each.

(3) Final Rating: pathogen, parasite or fellow traveler of Chinese mitten crab.

	Atlantic Coast		Pacific Coast	
Element	Rank	Uncertainty	Rank	Uncertainty
Arrival	High	Very High	High	Very High
Survival	Moderate	Very High	Moderate	Very High
Reproduction	Moderate	Very High	Moderate	Very High
Overall Establishment	**Moderate**	**Very High**	**Moderate**	**Very High**
Spread	Moderate	Very High	Moderate	Very High

Step 2: Determining the Consequences of Establishment of a Pathogen, Parasite or Fellow Traveler

(1) Impacts on native ecosystems both locally and within the region including disease outbreak, reduction in reproductive capacity, habitat changes, etc.

For the Chinese mitten crab there are two different types of pathogens, parasites, or fellow travelers that could pose a risk to Canadian ecosystems. The first is the oriental lung fluke, a parasite. Currently, this parasite lacks the necessary host to complete its life cycle but the consequence of this parasite is related to wildlife/human health. If the second intermediate host were to arrive in Canada then the impacts on mammalian health, including humans, would be very high. The second class of potential hitchhikers associated with Chinese mitten crab is epibiota associated with the mittens of this crab. For example, it has been documented that the North American crayfish plague fungus is carried by mitten crabs (Benisch, 1940). While this plague has the potential to impact freshwater biodiversity, the involvement of mitten crab as a vector is unlikely to have an effect on native crayfish species in Canada as this disease is endemic to these species. It is unknown how severely other invertebrate epibionts would affect any of the endpoints, including biodiversity, aquaculture or fisheries.

(2) Final Rating: pathogen, parasite or fellow traveler of Chinese mitten crab.

	Literature Results		Peer-review Results	
	Magnitude	Uncertainty	Magnitude	Uncertainty
Overall Consequences: Parasites	Low	Very High	Low	Moderate
Overall Consequences: Epibiota	Low	Very High	Low	Very High

Step 3: Summary of the Pathogen, Parasite or Fellow Traveler Overall Risk Potential for Chinese mitten crab.

	Atlantic Coast		Pacific Coast	
	Rating	Uncertainty	Rating	Uncertainty
Overall Risk: Parasites	Moderate	Very High	Moderate	Very High
Overall Risk: Epibiota	Moderate	Very High	Moderate	Very High

CONCLUSIONS

Chinese mitten crabs pose a variety of risks to Canadian waters. This species has been reported from Atlantic Canada but no known established populations exist. On the Canadian Pacific coast this species has not been reported. Overall, the risk posed by mitten crab on both the Atlantic and Pacific coasts is generally considered moderate, although the risk to river bank/flood protection was higher while genetic consequences was lower. The uncertainty was generally high to very high generally due to uncertainty about the establishment of Chinese mitten crab in Canadian waters.

Relatively little is know about pathogens, parasites or fellow travelers associated with Chinese mitten crab. For both the Atlantic and Pacific coasts the overall risk posed by pathogens, parasites or fellow travelers was considered moderate but the uncertainty about this ranking is very high due to the paucity of available data. There is an inverse relationship between the level of risk and its associated uncertainty when it comes to pathogens, parasites or fellow travelers of non-indigenous crab species, due largely to limited data. These fellow organisms have not been well studied thereby increasing the uncertainty of arrival, survival, reproduction, spread and potential impacts if introduced.

There is very little information available on the parasites, pathogens or fellow travelers associated with Chinese mitten crab due, in part, to the native range of this species. If this species has been extensively studied in China this literature (or access to experts) is unavailable. This contributes to the increased uncertainty when attempting to assess the risk posed by hitchhikers of this crab species.

In addition to data deficiencies about potential pathogens, parasites or fellow travelers of Chinese mitten crab a number of other data deficiencies also exist. For example, by being catadromous, the Chinese mitten crab possesses a complex life history strategy. It is known that this species must return to marine waters (at least 15‰) to spawn but we were unable to find any literature accounts of larval dispersal or behavior following spawning. Many crab zoeal stages have the ability to move vertically in response to light or food conditions but it is unclear what oceanographic range Chinese mitten crab larvae would use. This is an important data gap as larval dispersal in many crab species contributes to their maintenance of populations and provides an opportunity to exploit new environments. For example, the European green crab has used larval dispersal to invade Pacific Canadian waters and this vector has contributed to the spread of this species in both Atlantic and Pacific Canada. It is unknown how larval dispersal of Chinese mitten crab larvae could contribute to the spread of this species if it were to establish in Canadian waters.

The source of Chinese mitten crab introductions continues to elude researchers. With limited sampling from its native range it has not been possible to identify source populations of Chinese mitten crab which in turn has meant it has not been possible to fully resolve potential vectors and pathways. Further, the relative contributions from adult dispersal (e.g., live food trade) vs. larval dispersal (e.g., ballast water transport) remain unknown. Resolving the relative contribution of each to global invasion success would help resolve the relative contribution of potential dispersal vectors for Chinese mitten crab. The live import of Chinese mitten crab is banned but it is unknown how rigorous the enforcement is on this issue.

Commercial shipping, primarily ballast water, was identified as the most important vector for the initial introduction of this crab species. Commercial shipping data was available for a variety of vessel classes for the Pacific coast but no comparable data was available for the Atlantic coast. Given the large number of potential source populations for Chinese mitten crab in Europe, increased resolution of shipping data would allow refinement of potential areas of new introductions based on transit locations and potential areas of ballast water discharge. Also, there was very limited riverine or estuarine data available for much of Canada. Most monitoring programs are conducted offshore in the marine environment; hence away from estuaries and in-stream measurements are conducted only on major rivers. Increased monitoring of conditions on smaller rivers, especially in areas where Chinese mitten crab introductions are more likely (based on environmental niche modeling) should be a priority to refine invasion predictions and better characterize the risk of this non-indigenous crab species.

Monitoring efforts for aquatic invasive species likely need to be broadened, especially to include mobile fauna such as the crab species assessed here. Recent monitoring efforts in Atlantic Canada have focused on biofouling species such as non-indigenous tunicate species while relatively little effort has been directed to crab species. Trapping for green crab has been an integral component of intertidal aquatic invasive species monitoring in Pacific Canada and the methodology would be easily transferable. Further, there is an increased need to increase stakeholder participation in monitoring programs for invasive species. For example, the shellfish aquaculture industry has been engaged in recent years to deal with non-indigenous tunicate species. It is probable that eel fishermen in Atlantic Canada would be one stakeholder group most likely to encounter Chinese mitten crab migrating between freshwater and marine environments. Raising awareness with these stakeholders (and others) will increase our understanding of potential invasions and may allow the implementation of management measures.

The risk assessment for Chinese mitten crab presented here represents a starting point, providing scientific advice for decision makers, managers and policy makers who have to manage, control or mitigate the potential impact of these non-indigenous species. The scientific advice contained in this document is meant to inform the overall risk analysis framework that includes socio-economic considerations and should not be considered independent of this framework. The overall risk analysis framework for the Canadian Department of Fisheries and Oceans is currently under development. Also, the information contained within this document, and ancillary accompanying documents, may need to be re-visited as more information is gained and identified data gaps filled. For example, the predictions of environmental suitability were based on current native (estimated) or invaded distributions, therefore highlighting areas having the same environmental conditions as those where the species has already been found. One potential limitation to this approach is that it could underestimate the potential habitat available if the current invaded range is not fully representative of its potential range. As the species spreads to new areas it is possible the predicted suitable environments also will increase as the true environmental niche becomes more apparent.

The risk assessment presented here focused on the risk posed to either the Canadian Atlantic or Pacific region. If one wanted to look at the risk posed within a region, each province within the Atlantic region for example, an additional risk assessment should be undertaken. Although the impacts would be similar, the probability of establishment (e.g., probability of arrival, survival, and reproduction) could differ depending on available vectors and pathways. Also, we used the best available data for the ecological niche modeling but the modeling was conducted at a relatively large spatial scale. Additional, smaller-scale data could be available that might better identify micro-scale habitats of greater (or lesser) concern.

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APPENDIX A:
Participants at the National Peer-review Workshop for the Risk Assessment of Two Crab Species in Both Atlantic and Pacific Canadian Waters

Participant	Organization
Thomas Therriault	DFO – Pacific Region (PBS)
Leif-Matthias Herborg	DFO – Pacific Region (PBS)
Andrea Locke	DFO – Gulf Region (GFC)
Christopher McKindsey	DFO – Quebec Region (IML)
Ted Grosholtz	University of California – Davis (Reviewer)
Deborah Rudnick	Integral Corporation (Reviewer)
Graham Gillespie	DFO – Pacific Region (PBS) (Reviewer)
Joe Roman	University of Vermont (Reviewer)
Marcel Bernard	Quebec Government (MRNF)
Yves de Lafontaine	Environment Canada
David Delaney	McGill University
Trevor Floyd	DFO – NCR
Tonya Furlong	DFO – NCR
Saba Khwaja	DFO – NCR
Julie Lavallee	DFO – Quebec Region
Brian Leung	McGill University
Cynthia McKenzie	DFO – Newfoundland Region (NWAFC)
Mikio Moriyasu	DFO – Gulf Region (GFC)
Darlene Smith	DFO – NCR
Melisa Wong	DFO – Maritimes Region (BIO)
Brian Bickford	Translator

APPENDIX B: Definitions for Vector and Impact Questions used in the Expert Survey

Vector Importance

Very low: Chinese mitten crabs have not been demonstrated or believed to utilize this vector. Does not require management action.

Low: Chinese mitten crabs are unlikely to spread by this vector. May require efforts to minimize spread.

Moderate: Chinese mitten crabs can spread by this vector in favorable circumstances. Management could provide a reduction of spread.

High: Chinese mitten crabs have extensively used this vector. Management would be important for a reduction of spread, but none has been attempted.

Very high: Chinese mitten crabs have extensively used this vector despite extensive management efforts.

Vector Uncertainty Levels

Very high uncertainty: Little to no information; expert opinion based on general species knowledge.

High uncertainty: Limited information; third party observational information or circumstantial evidence.

Moderate uncertainty: Moderate level of information; first hand, unsystematic observations.

Low uncertainty: Substantial scientific information; non peer-reviewed information.

Very low uncertainty: Extensive scientific information; peer-reviewed information.

Impact Level

Positive A positive impact. Improvement of the factor in question.

Very low negative No measurable impact. Consequences can be absorbed without additional management action.

Low negative A measurable limited impact. Disruption to the factor in question, but reversible or limited in time, space, or severity. May require management effort to minimize.

Moderate negative A measurable widespread impact. A widespread disruption to the factor in question, but reversible, or of limited severity, or duration. Can be managed under normal circumstances.

High negative A significant impact. A widespread disruption to the factor in question that persists over time, or is likely not reversible. Will require effective management or adaptation of procedures.

Very high negative A critical impact. Extensive disruption to the factor in question, that is irreversible. May already be unmanageable or will become so unless effective management is immediately put in place.

Estimated Probability if Impact

Unlikely Impact will only occur in exceptions or is not expected

Possible Impact could occur in some circumstances

Likely Impact will probably occur in most circumstances

Almost certain Impact is expected to occur in most circumstances

Certain Impact has been observed to occur