

# Marine Crustacean Invasions in North America: A Synthesis of Historical Records and Documented Impacts

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**Abstract** We examine the history and relative importance of marine crustacean invasions for North America. Nearly 400 non-native species of invertebrates and algae have established populations in marine and estuarine waters of North America. Of these documented invasions, 28% are crustaceans, contributing the largest number of species of any taxonomic group. Crustaceans also dominate non-native species richness on each coast of North America, but there are strong differences in the total number of non-native species and in their taxonomic distribution among coasts. Crustaceans contribute prominently to the current knowledge base about marine invasions, due both to the large number (proportion) of documented introductions and also the extent of research on the group; they are thus a potentially important model for understanding marine biological invasions in general. Using an analysis of available literature, we evaluate what is known about the impacts of 108 non-native crustaceans in North America. Ecological and economic impacts are reported for many (28%) of these species, but they are rarely well documented, resulting in low certainty about the magnitude, spatial scale, and temporal scale of effects.

## 1 Introduction

Biological invasions by crustaceans are a conspicuous feature of coastal marine ecosystems throughout the world. This prominence results from a combination of multiple factors, including the relatively large body size and good taxonomic (and biogeographic) resolution that exists for many species compared to some other

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taxonomic groups (Cohen and Carlton 1995; Carlton 1996; Ruiz et al. 2000). In addition, crustacean invaders can often achieve high abundances, further increasing the likelihood of detection and observation. All of these attributes are exemplified by many crab and barnacle species that are frequently recognized introductions, such as the European shore crab *Carcinus maenas* and the Chinese mitten crab *Eriocheir sinensis*.

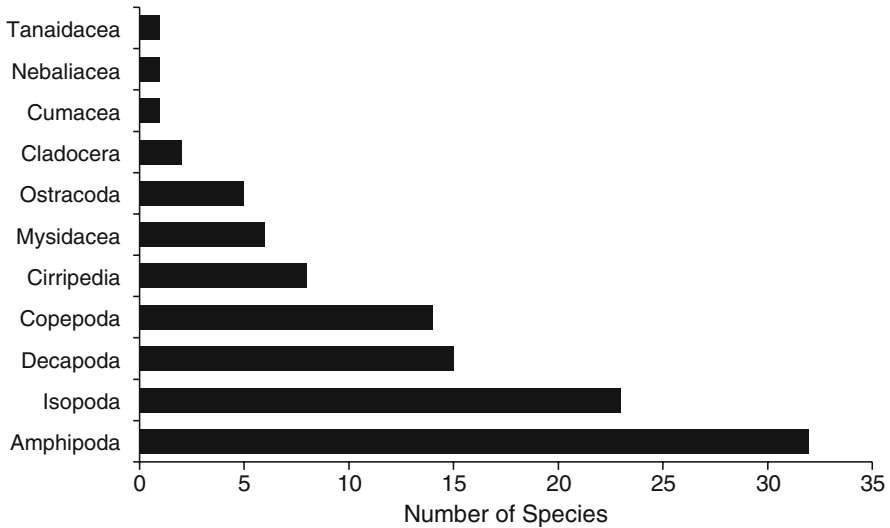
It is therefore no surprise that crustaceans are among the most studied of all marine invaders and often comprise a large proportion of the documented non-native species in well-studied regions of the world (Cohen and Carlton 1995; Reise et al. 1999; Orensanz et al. 2002; Bouley and Kimmerer 2006; Hewitt et al. 2004; Galil 2008). Research on non-native species of crustaceans spans a wide range of topics, from population dynamics and evolutionary biology to community ecology and economic consequences (Vermeij 1982; Seeley 1986; Grosholz et al. 2000; Talley et al. 2001; Lohrer and Whitlatch 2002; Floyd and Williams 2004; Hollebone and Hay 2008). Given the scope and extent of this past work, crustaceans provide an important model for understanding invasion patterns and processes.

In this chapter, we present a brief overview of the current state of knowledge about crustacean invasions for marine and estuarine waters of North America, excluding Mexico. We synthesized and analyzed occurrence records for marine species to identify non-native species that have been documented in North America, evaluating species considered to have established populations. The results were documented in a database (NEMESIS 2009) and used to characterize (a) the identity, distribution, and native region for non-native crustaceans documented among the Atlantic, Pacific, and Gulf coasts of North America, (b) the relative importance of crustaceans to overall non-native species richness documented for each coast, and (c) the impacts (effects) that have been reported for North America.

## 2 Taxonomic and Geographic Distribution of Non-native Crustaceans

We identified 108 non-native species crustaceans that were classified as having established populations in marine and estuarine (tidal) waters of North America, including the continental United States and Canada (Appendix 1). As noted in previous analyses (Ruiz et al. 2000), crustaceans make the single largest contribution of any taxonomic group to the number of documented non-native species in North America. In our current analysis, we classified 381 non-native species of invertebrates and algae (i.e., excluding vertebrates and vascular plants) as having established populations in tidal waters of North America. Thus, crustaceans comprised 28% of this total non-native species richness on a continental scale.

The largest contribution of non-native crustaceans came from amphipods, providing 30% of documented crustacean invasions in North America (Fig. 1). Three other groups each contributed strongly to the total species richness: isopods (21%), decapods (14%), and copepods (13%). Other groups of crustaceans each contributed less than 10% of the total species, with barnacles, mysids, and ostracods providing the most (7%, 6%, and 5%, respectively; Fig. 1).

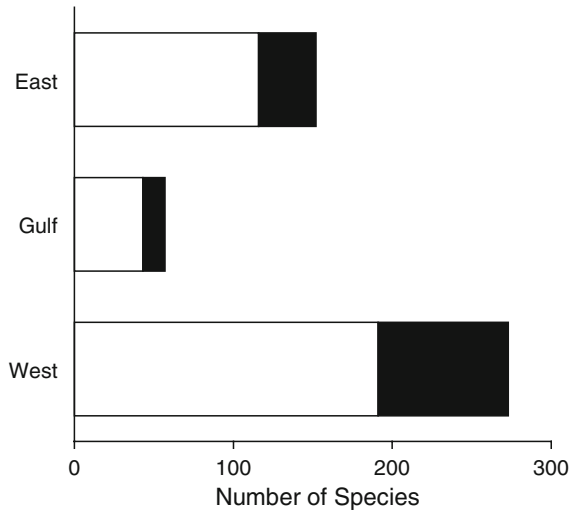


**Fig. 1** Taxonomic distribution of non-native crustaceans in tidal (marine and estuarine) waters of North America. Shown are the numbers of species in each taxonomic group classified as non-native and established in North America

## 2.1 *Number of Species by Coast*

There are strong differences in the total number of non-native species among the three coasts of North America (Fig. 2). Far more non-native species have been documented for the West coast than the other two coasts, when considering established populations of invertebrates and algae. Despite such a disparity in overall numbers, the relative contribution of crustaceans to totals on each coast is similar: 42% of non-native species on the West coast, 33% on the Gulf coast, and 31% on the East coast (Fig. 2). Nonetheless, 75% of all non-native crustaceans are known from the West coast alone, and far fewer are documented on the Gulf coast (13%) and East coast (33%), with some species shared among coasts (Appendix 1).

Several factors may contribute to this disparity in the total number of non-native crustaceans and other taxa documented among coasts. One of these involves the quality of the historical record and knowledge about biogeography, both of which differ by coast. Marine biological studies on the East and Gulf Coasts began in the early-mid-1800s, centuries after the beginning of extensive European trade and shipping (1500s–1600s, Carlton 2003). Due to this long gap, many species may have invaded the Atlantic coast of North America before the biota were catalogued (Carlton 2003). In contrast, biological collections and studies began on the West Coast in the late 1800s, only few decades after the beginning of extensive settlement and shipping (mid-1800s, Carlton 1979), although we note that the West coast, too, experienced early contact (beginning in the 1500s) with European shipping. Such geographic differences in relative timing of events may greatly affect the ability to detect non-native species (Ruiz et al. 2000).



**Fig. 2** Proportion of non-native species for each coast of North America that are crustaceans. *Bars* indicate total number of invertebrate and algal species that are classified as non-native and established in tidal waters on each coast; *shaded areas* indicate numbers (proportions) that are crustaceans

Specific characteristics of species transfer mechanisms have also affected observed differences in non-native species richness among coasts in at least two ways. Both the magnitude and geographic source(s) of species transferred by human means have clearly differed among coasts, affecting the species pool and the number of propagules (individuals) delivered. This variation is perhaps most pronounced for oyster transfers and their associated biota. Massive numbers of oysters were transferred to the West coast, first from eastern North America (the Eastern Oyster, *Crassostrea virginica*) and then from Asia (Pacific Oyster, *C. gigas*), resulting in a large number of invasions by associated biota (Carlton 1979; Cohen and Carlton 1995; Miller et al. 2007). In contrast, transplants of oysters to the East and Gulf coasts from other global regions have been very limited in scale, occurring later in time with more care to prevent movement of associated species (Loosanoff 1955; Hidu and Lavoie 1991). Some transfers of native oysters (*C. virginica*) along the Atlantic coast have resulted in introductions (e.g., *Loxothylacus panopaei*, from the Gulf of Mexico to Chesapeake Bay, Hines et al. 1997). Nonetheless, while oyster introductions have been a major source of invasions to the West Coast of North America, relatively few species are attributed to this mechanism on the East or Gulf Coast.

As with oysters, strong differences in commercial shipping have contributed to variation in non-native species richness among coasts, especially with respect

to source region. For example, in recent time, most overseas ship arrivals to the West coast came from ports in Asia and other Pacific Rim countries, but those to the East and Gulf coasts have been mainly from Atlantic ports (NBIC 2009). Independent of potential differences in the magnitude (number of species and densities) of organism transfers among regions, the different origin of vessel traffic indicates that a different pool of species is delivered to each coast of North America. This said, exceptions to this general pattern occur, and may deliver notable species to the “opposite” coast, such as the Asian shore crab *Hemigrapsus sanguineus* that invaded the East coast in the 1980s (Lohrer and Whitlatch 2002).

Although there are conspicuous differences in the supply of propagules among coasts, it is also possible that these geographic regions differ in susceptibility to invasions. It has been suggested that West coast estuaries are more susceptible to invasions than those elsewhere because of disturbance or a depauperate native fauna (Cohen and Carlton 1998). This hypothesis remains to be tested in a way that controls for many of the other confounding factors or differences among locations (Ruiz et al. 1999, 2000).

It has also been suggested that the West coast is relatively susceptible to invasions, especially from Asia, due to climatic regime (Vermeij 1991; Chapman 2000). In the north-temperate zone, the eastern shores of oceans (Europe, western North America) have marine-dominated climates, with milder winters and summers, while the western shores (Asia, eastern North America) have continental-dominated climates, with a wider temperature range. Species that have evolved in the latter regions (Northwest Atlantic, Northwest Pacific) may be superior colonists, while species native to marine-dominated climates (Northeast Atlantic, Northeast Pacific) may have difficulty surviving the wide temperature range in continental climates. Chapman (2000) considers this an explanation for a west-to-east pattern of invasions for peracarid crustaceans in North America, and Carlton (1999) has found a similar pattern in molluscs.

## 2.2 *Salinity Distribution of Species by Coast*

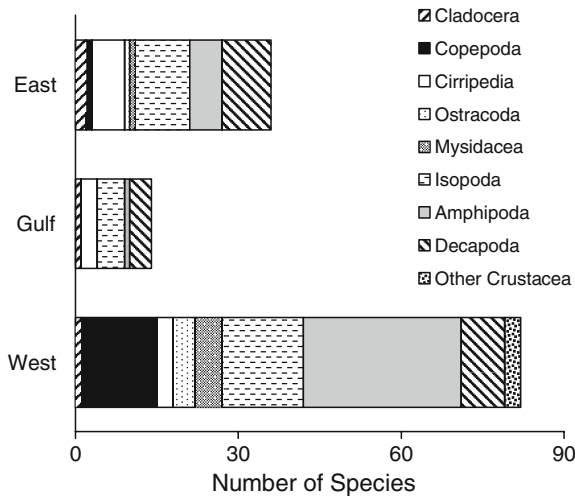
For each coast, the majority of the non-native crustaceans in our analyses occur in marine waters, ranging from 65% to 78% (Appendix 1). A small subset of species is restricted to tidal freshwater reaches of estuaries on each coast, exhibiting a very narrow range (15–16% of the crustaceans) among coasts. The West coast has more than twice the frequency of brackish water specialists (18% of species) than the East or Gulf coasts (5% and 8%, respectively). This difference results largely from the greater number of copepods and mysids that have colonized brackish water on the West coast compared to other coasts, where these groups were relatively rare (see below for further discussion).

### 2.3 Taxonomic Distribution by Coast

A striking difference exists among coasts in the relative frequency of different taxonomic groups within the non-native crustaceans (Fig. 3). On the West coast, a disproportionately large percentage of the total is comprised of amphipods (35%) and copepods (17%) compared to the other coasts. In contrast, amphipods contribute 7% and 17% of the non-native crustaceans for the Gulf and East coast, and copepods were 0% and 3% of the totals for these respective coasts. Mysids are also more prevalent on the West coast (five species, 6% of crustaceans) compared to the Gulf coast (none) and East coast (one species or 3%).

For copepods and mysids, the differences among coasts are attributed in large part to invasions from Asia. The estuarine copepod and mysid fauna of the coast of Asia includes a substantial contribution from a diverse fauna, adapted to low-salinity brackish waters, many of which range into temperate waters. Fourteen of these species (ten copepods, four mysids) have been introduced to West Coast estuaries in ballast water (Cohen and Carlton 1995; Orsi and Ohtsuka 1999; Bollens et al. 2002; Modlin 2007; Cordell et al. 2008), representing 71% of copepod introductions and 80% of mysid introductions to this coast. In contrast, only one copepod and one mysid are known introductions to the Gulf and East coasts combined (Appendix 1).

The paucity of copepod invasions for the entire Atlantic coast is especially surprising, given the magnitude of shipping and ballast water discharge at major ports along this coast (NBIC 2009). Although ballast water is considered the source for most copepod invasion along the West coast, a similar signal is completely lacking



**Fig. 3** Contribution of different taxonomic groups to non-native crustaceans for each coast of North America. Shown are the numbers of species in the respective taxonomic groups that are considered non-native and established in tidal waters on each coast

for the East and Gulf coast, where the only reported invasion is a freshwater parasitic copepod on fish (*Lernaea cyprinacea*). Moreover, the only documented non-native marine zooplankton species established on the East Coast is the European mysid *Praunus flexuosus* (Wigley 1963).

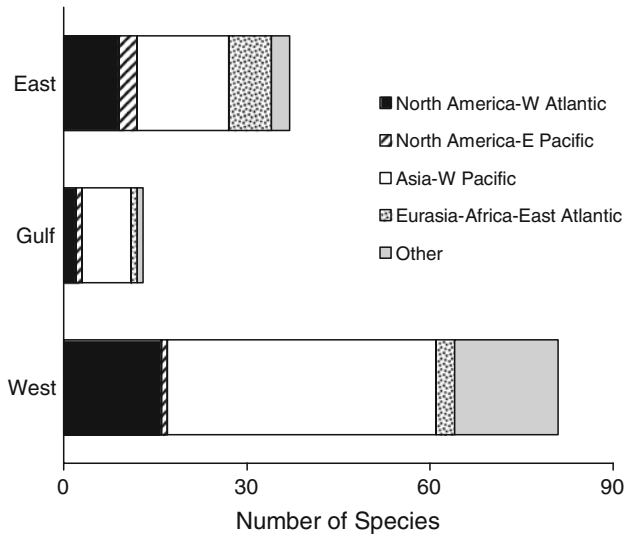
Based on past and current shipping patterns, most overseas ship arrivals and ballast discharge to the East coast have come from Europe, whereas that to the West coast has been from Asia (NBIC 2009; Ruiz, 2005). It is noteworthy that the copepod fauna of Europe is considered relatively low in diversity, with many circumpolar and amphi-oceanic species and species complexes (Frost 1989; Bradford 1976; Lee 2000). While many of the copepods introduced to West coast estuaries from Asia are morphologically distinct and easily recognized (Orsi and Ohtsuka 1999), the species pool in Europe reaching the East Coast via ballast water of ships is more similar morphologically to the native fauna (Fofonoff and Ruiz, 2003). It is possible that some early introductions of European copepods have been overlooked, especially if species complexes disguise a richer biota than is presently recognized.

For amphipods, some of the same issues appear important in the observed disparity among coasts. Asia was an important source (native region) for amphipods on the West coast, and so was the Atlantic, resulting from transfers by oysters and ships (Cohen and Carlton 1995; NEMESIS 2009). Atlantic and Asian amphipods arriving on the West Coast appear to have often been morphological distinct and readily recognized from native biota (Carlton 1979; Chapman 1988, 2007). In contrast, a number of amphipod species, especially those building tubes on solid surfaces (e.g., Corophiinae, *Jassa marmorata*; *Ampithoe valida*; *Erichthonius brasiliensis*) are found on both sides of the Atlantic (Lincoln 1979; Conlan 1990; Bousfield and Hoover 1997). It is likely that some early introductions of European fouling-community amphipods to the East Coast have been overlooked, since they could have happened centuries before the onset of biological studies.

More generally, the frequency differences observed for taxonomic groups among coasts results from variation in (a) the historical supply of propagules, (b) susceptibility to invasions, and (c) detection of non-native species. The relative importance of each of these is still under debate for crustaceans and all other taxa, as discussed above (see Sect. 2.1). The patterns observed for copepods and other ballast-mediated invasions serve to further underscore the importance of propagule source in constraining the species pool and taxonomic resolution. There is also the suggestion that the biota from some regions may be superior colonists, such as species arriving from Asia to the West coast of North America (Vermeij 1991, 1996; Chapman 2000).

## 2.4 Native Region by Coast

In considering the native region of crustaceans on a broad-scale (Fig. 4), most species are from Asia and the western Pacific, ranging from 41% to 62% of all crustaceans per coast. North America itself is the second largest native region for crustacean



**Fig. 4** Contribution of different native regions to non-native crustaceans for each coast of North America. Shown are the numbers of species from the respective broad-scale native regions that are considered non-native and established in tidal waters on each coast

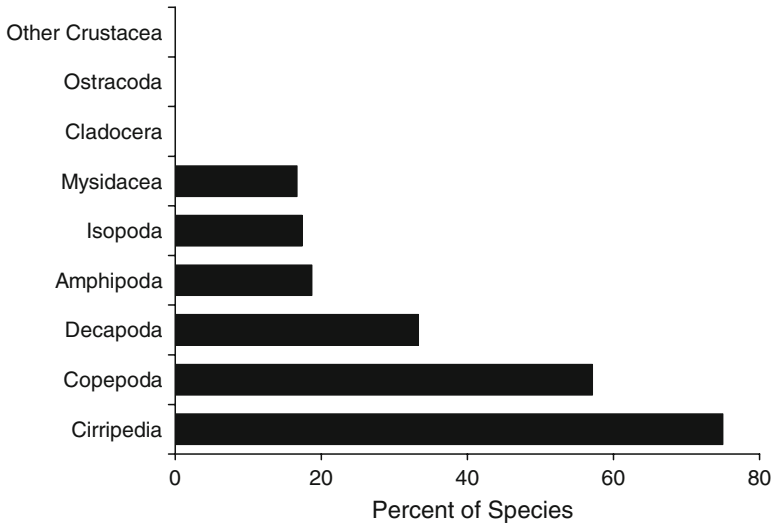
invasions, contributing 21–32% of species with the vast majority on each coast from western Atlantic coast. The eastern Atlantic (including Eurasia and Africa) was the third largest native region for all three coasts of North America, being greatest for the East coast (19% of species) and lower for the Gulf and West coasts (8% and 4%, respectively). The native region for the residual species was classified as other, including other regions and those of unknown origin.

While the prominence of Asia and western Atlantic reflect the history of shipping and oyster transfers (as discussed above), the contribution of Asia across all regions is somewhat surprising when considering the historical and current trade patterns. For the East coast, this results from the combination of direct introductions as well as secondary introductions via Europe. The latter is illustrated by the recent introduction of the Chinese mitten crab *Eriocheir sinensis* to the East coast, where genetic data suggest Europe as the likely source population (Ruiz unpubl. data).

### 3 Impacts of Non-native Crustaceans

For all of North America, an impact was reported to occur in marine and estuarine waters for 30 of the 108 crustacean species, representing 28% of all species (Appendix 1). Here, we recorded an impact if there was a significant change attributed to the non-native species, causing either (a) a detectable change in composition or population size(s) of resident species or (b) economic impact, including effects





**Fig. 5** Percent of non-native species in each crustacean group that are reported to have impacts in tidal waters of North America. See Fig. 1 for total number of species in each group

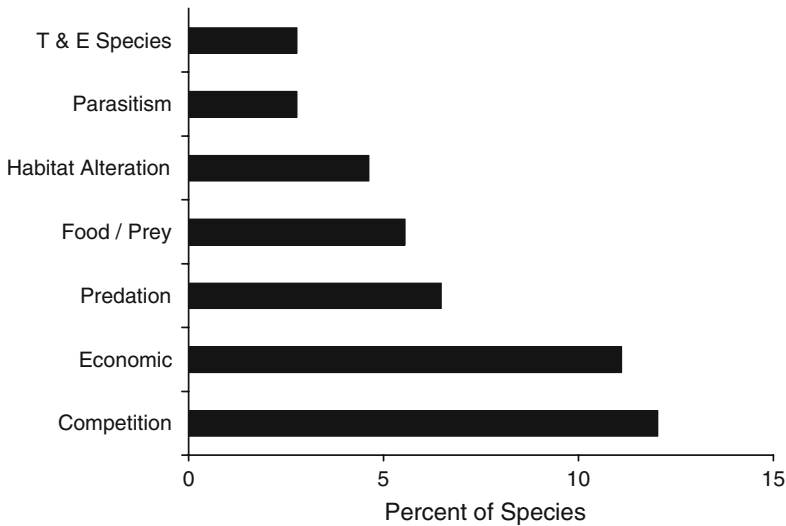
on fisheries resources, agricultural products, infrastructure (e.g., docks, piers, dams, water supply), power plants, shipping, and recreation. As a first analysis, we considered impact as a binary condition, which was either reported or not reported, regardless of information type and impact magnitude (addressed separately below) or whether explicitly tested.

Considering only marine and estuarine waters of North America, some type of impact was reported most frequently for introduced barnacles (75% of species), copepods (57%), and decapods (33%) (Fig. 5; see also Appendix 1). Impacts were reported for 17–19% of the amphipod, isopod, and mysid species. No impacts were reported for cladocerans, ostracods, or other species of crustaceans.

When expanding our analysis to include the same non-native species in non-tidal freshwater (i.e., lakes and rivers), another six species have been reported to have impacts, including five in North America and one on another continent (Appendix 1). These included three species of decapods, two species of amphipods, and one species of cladoceran. As such impacts were not reported for marine and estuarine waters, we have excluded them from further analyses.

### 3.1 Impact Type

Figure 6 shows the frequency of impact types reported for tidal waters of North America for all 108 non-native crustacean species. Slightly over 10% of species were reported to have competition or economic impacts. Approximately 5% of species were reported to have effects as a result of predation (including herbivory),



**Fig. 6** Frequency of impact types reported for crustaceans in tidal waters of North America. Shown are the percent of species reported to have impacts in seven broad impact categories (T & E = threatened and endangered). Species may be included in more than one category

providing a food/prey resource, or altering habitat. Effects on host populations by parasitism was reported for 3% of species, and effects on threatened or endangered (T & E) species were reported for 3% of species. These categories were not mutually exclusive, in that more than one impact type was reported for 13 of the 30 species with reported impacts (Appendix 1). Although we also considered changes in ecosystem processes (e.g., nutrient cycling) as a possible impact category, none of the crustaceans were reported to have a significant impact of this type.

### 3.2 Information Type and Effect Magnitude

Most of the impacts reported were based upon qualitative observation, correlated changes associated with the arrival or abundance of a non-native species, or changes inferred from understanding the ecology of a species (Appendix 2). For seven (23%) of the 30 species with reported impacts, impact assessments were based on laboratory or field experiments. The latter included three decapods (*Carcinus maenas*, *Hemigrapsus sanguineus*, *Petrolisthes armatus*) and a single species each of amphipod, isopod, barnacle, and copepod (*Microdeutopus gryllotalpa*, *Sphaeroma quoianum*, *Loxothylacus panopaei*, *Tortanus dextrilobatus*, respectively).

We estimated the effect size or magnitude for each of the species with reported impacts, and approximately half (14) of the 30 species were considered to cause change(s) in excess of 50% in other resident populations or to have economic effects.

This was a coarse-level assessment, in which we estimated the magnitude of changes by impact type that were reported in the literature. Our goal was to gain some indication of the perceived effect size by classifying observed changes into one of five categories of increasing effect size (see Appendix 2; this is an initial application of methods being developed by Dahlstrom). Thus, this is not a precise measure but instead a rough index of reported effect size, on some spatial and temporal scale (see [Conclusions](#)).

For some species, the actual effect size was not explicitly stated. In some of these cases, we generated an estimate based on information provided. In other cases, there was simply too little information to obtain a reasonable estimate, and these were classified as “undescribed or unassessed”, occurring for 10 of the 30 species. This does not mean that the species is considered to have an insignificant impact, only that that effect magnitude was elusive. This situation is perhaps best illustrated by barnacles, many of which are known to have significant economic impact as biofouling organisms, affecting vessels (e.g., increased fuel consumption, hull maintenance) and water intake systems in North America and elsewhere. While the local effect of barnacles on an individual vessel or power plant can be severe, the impacts are often caused by a broader community of species that include barnacles, and effects are occurring on a global scale. Our ability to examine such partial contributions or cumulative effects was limited in the current classification scheme.

### 3.3 *Certainty*

We used a categorical index to assess the strength of inference about the magnitude of reported impacts. Our approach relied on information type (above), and certainty or confidence in reported estimates of effect magnitude was considered low in the absence of quantitative data or when the ability to partition effects among multiple (confounding) factors was limited. We assigned a certainty score from 1 to 3 (low to high) for each reported effect magnitude x impact type, for the 30 species in which an impact was reported (Appendix 3).

At the present time, the level of certainty or confidence about the effect magnitude of non-native crustaceans is very limited. We classified 8 (27%) of the 30 species as having a high level of certainty about the reported effect magnitude for at least one of the impact types. This included primarily species for which there were quantitative experimental data that evaluated ecological effects (three decapods, one copepod, one amphipod) and those which caused conspicuous erosion or destruction of docks (three isopods). All other species were classified as having low certainty about the reported effect magnitude for all impact types.

This analysis does not imply that these effect magnitudes are incorrect or did not occur, but only that the information available is too limited to have confidence in these reports. Assigning impacts to an individual invading species is especially difficult when environmental conditions, species assemblages, and foodwebs are all

undergoing changes driven by multiple causes. Observed changes that are coincident or correlated with invasion dynamics are clearly useful, but the ability to attribute cause of a single factor is confounded by the many other changes that are occurring (Ruiz et al. 1999).

This complexity is illustrated in the fresh and brackish Delta regions of the San Francisco Bay estuary, where five non-native species of planktonic copepods (*Acartiella sinensis*, *Pseudodiaptomus forbesi*, *P. marinus*, *Tortanus dextrilobatus*, and *Limnoithona tetraspina*) and two non-native mysids (*Hyperacanthomysis longirostris*=*Acanthomysis bowmani*; *Orientalomysis aspera*=*A. aspera*) appeared and became abundant or dominant over the course of approximately 7 years, from 1987 to 1993 (Orsi and Walter 1991; Cohen and Carlton 1995; Modlin and Orsi 1997; Orsi and Ohtsuka 1999). The calanoid copepod *Eurytemora affinis*, probably an early introduction to the estuary (Lee 2000; Orsi 2001), had been a dominant mesozooplankton (Ambler et al. 1985) and an important component of the diet of larval and planktivorous fishes in the Delta (Nobriga 2002; Nobriga and Feyrer 2008; Bryant and Arnold 2007). Within 2 years of its first detection, *P. forbesi* had become the most abundant calanoid in fresh and oligohaline regions of the Delta, while *E. affinis* had declined. Similarly, the native mysid *Neomysis mercedis*, another major prey item for fishes, had declined and was largely replaced by the two introduced mysids, *H. longirostris* and *O. aspera*, first collected in 1993 (Modlin and Orsi 1997).

The changes in species composition in the plankton coincided with declines in recruitment of two important fish species, the introduced Striped Bass, *Morone saxatilis*, a major game fish in the Bay, and the native, endangered Delta Smelt, *Hypomesus transpacificus*. Larvae of striped bass fed selectively on the copepod *E. affinis* in experiments, apparently because of superior escape abilities of *P. forbesi* (Meng and Orsi 1991). *Eurytemora affinis* was also considered to be a higher-quality prey, over *P. forbesi*, for all stages of the smelt (Moyle et al. 1992; Nobriga 2002). However, since *P. forbesi* has become dominant, it is now the primary copepod in the diet of both fish species (Hobbs et al. 2006; Bryant and Arnold 2007). The replacement of the mysid *N. mercedis* by the two exotic mysids is also considered to be adverse for juvenile striped bass, since the introduced mysids are smaller, and so require more search effort (Nobriga 2002; Feyrer et al. 2003).

At first glance, these drastic changes in species dominance and fish recruitment might be attributed to superior competitive abilities of the planktonic invaders. However, they have followed a drastic change in the estuary's foodweb, caused by another invader, the Asian brackish-water clam *Corbula amurensis*, which appeared in the Bay in 1986, and quickly developed huge biomasses, whose suspension-feeding drastically decreased phytoplankton biomass and shifted energy and nutrients from the plankton to the benthos (Alpine and Cloern 1992; Nichols et al. 1990). The decrease in phytoplankton and zooplankton biomass, and decreased planktivorous fish recruitment, has persisted to the present, and has been termed 'pelagic organism decline' (Sommer et al. 2007; Baxter et al. 2008).

The replacement of *E. affinis* by *P. forbesi* appears to be partly due to the superior ability of its nauplii to escape the feeding currents of the Asian Clam (Kimmerer et al. 1994). The role of competition in the species replacement is not clear. However, *P. forbesi* did rapidly replace a previous invader, *P. inopinus*, in the

Columbia River estuary (Sytsma et al. 2004; Cordell et al. 2008). Similarly, the mechanism of species replacement of the native mysid *N. mercedis* by the two exotic mysids has not been studied. Competition has been suggested, but the invading mysids may be better adapted to the altered foodweb, or more tolerant to other environmental changes in this highly disturbed estuary. The invading species maintain a much smaller biomass than *N. mercedis*, probably reflecting the overall plankton biomass decline (Feyrer et al. 2003).

Thus, ecological impacts of the introduced copepods and mysids in the San Francisco estuary are reported, and may have a large effect magnitude, but certainty remains low. The changes in species composition and fish recruitment associated with the invasions occurred not just in the context of the *Corbula* invasion, but also in an environment affected by many anthropogenic disturbances, including pollution, water diversions, fishing pressure, and natural drought/flood cycles, resulting in drastic changes in river flow, salinity, suspended sediment, and water quality (Hobbs et al. 2006; Sommer et al. 2007).

## 4 Conclusions

In North America, crustaceans constitute a dominant component of the documented non-native marine diversity, whether considered at the continental scale or on individual coasts. While we have summarized the relative importance (percent contribution) of crustaceans to the recorded non-native diversity, as well as the contributions of different crustacean groups to these spatial scales, we advise some caution in interpreting these results. Certainly many invasions have gone undetected, creating the potential for strong biases in the available record, and understanding the scale and effects of such biases remain a significant challenge for invasion biology (Carlton 1996; Ruiz et al. 2000; Hewitt et al. 2004). Nonetheless, crustaceans provide a significant amount of the available knowledge about invasions in coastal marine systems.

Our analysis indicated that crustaceans not only contribute to the overall spatial patterns observed but also provide an important barometer for invasion dynamics. The relative difference in total non-native species richness among coasts was also reflected in the crustaceans, contributing 31–42% of the total on each coast (Fig. 2). The invasion record for crustaceans indicates the operation and importance of different transfer mechanisms in space and time. This record appears to have been particularly sensitive for detection of ballast-mediated introductions on the West coast, signaling the increased trade with Asia and delivery of low-salinity ballast water over the past few decades. The observed pattern for ballast introductions raises interesting hypotheses about the importance of source(s) and why a similar spike in ballast water introductions is not evident along the East and Gulf coasts, especially for copepods and mysids. In short, the crustaceans provide a good model for testing ideas about coastal invasions.

This study found that significant impacts were reported within tidal marine and estuarine waters of North America for at least 28% of the 108 non-native crustacean

species documented here, spanning a range of impact types. Importantly, this analysis does not imply that the other species have no impact or even that effects of species are restricted to those observed. We have merely attempted to characterize effects that were observed at some spatial and temporal scale.

While impacts from crustacean invasions occur in North America, and some are well documented (e.g., effects of predation, biofouling, boring, and erosion), it is particularly challenging to understand the magnitude and spatial scale of effects. For most cases (72% of species with reported impacts), there was a low level of certainty about the magnitude of effects reported at some scale, due largely to (a) the lack of quantitative data and (b) the potential confounding effects of many other factors associated with observed changes.

Use of quantitative experiments can help address the issue of certainty in many cases, but the spatial and temporal extent of impacts still remains difficult to estimate in the field. Most experiments or studies are conducted over relatively small spatial and temporal scales. However, the application of these results to broader scales is poorly understood, because effects are expected to vary in both space and time, due to changes in population characteristics, local conditions, and scale-dependent processes (Diamond 1986; Parker et al. 1999; Ruiz et al. 1999).

The issues of variation and scale are not new or unique to the analysis of invasion impacts. While various approaches can be considered to integrate or represent effects across a species range (e.g., Parker et al. 1999), each requires an adequate foundation of measures that appears to be limited at the present time, even for those species where impacts are known. This is illustrated by the European crab *Carcinus maenas*, one of the best studied invaders with well-documented impacts in multiple geographic regions. For example, it is evident that the crab has caused significant population and community effects as an introduced predator in eastern North America, western North America, and Australia in a wide range of habitats (Glude 1955; Grosholz et al. 2000; Walton et al. 2002; Ross et al. 2004; Trussell et al. 2004; Griffen and Byers 2009; Kimbro et al. 2009). There are unusually good quantitative estimates in many of these cases, but most are limited in spatial scale and do not assess geographic variation. Yet, such measures are needed to evaluate the full scope of identified effects across a geographic range.

Overall, increasing quantitative measures for non-native species impacts is a high priority for invasion ecology. While invaders are a conspicuous and growing component of marine and estuarine communities (Cohen and Carlton 1998; Ruiz et al. 2000), there are many critical gaps in our understanding of ecological and economic effects for most species. In advancing research to address these gaps, it would be particularly useful to implement approaches that address the issues of spatial and temporal variation. Selecting a few species for standardized measures and experiments across multiple locations would be most valuable and an obvious next step in this direction. Crustaceans offer an excellent model for this purpose, due to (a) clear impacts that have been documented for some species, (b) the widespread nature of many non-native species (both within North America and globally), and (c) the extensive background knowledge about the biology and ecology of many groups (e.g., crabs and barnacles). In addition, past studies demonstrate

that many species are conducive to experimental manipulations that quantify the magnitude of effects and can be replicated in space and time.

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## Appendix 1

Classification of distribution and impact type for non-native species of crustaceans considered established in tidal (marine and estuarine) waters of North America. Information included is as follows:

- (a) **Taxonomic Group and Species** is provided for each crustacean classified as non-native and established in North America.
- (b) **Coast** indicates which of the three North American coasts (P)acific, (A)tantic, or (G)ulf; asterisk (\*) indicates native to part of the coast indicated; (Cr)ypto-genic indicates cryptogenic to Atlantic and Gulf coasts.
- (c) **Salinity Range** characterizes known salinity distribution of the species as either Marine (M), Brackish Specialist (B), Freshwater (F), or Catadromous (C).
- (d) **Impact Type** indicates the type of impact reported separately for each species in each of three habitat regions, including (1) marine and estuarine waters of North America, (2) freshwater inland lakes and rivers in North America, and (3) other global regions where the species has been introduced (i.e., not including the native region). For each of these habitat regions, the impact type is classified broadly into the following categories: P = effect(s) through predation including herbivory, C = effects through competition, X = effects through parasitism, F = effects as food or prey, H = effects through habitat alteration, T = effects on threatened or endangered species, and E = economic effects on fisheries resources, agricultural products, infrastructure (e.g., docks, piers, dams, water supply), powerplants, shipping, and recreation. Occurrence of each impact type is indicated in individual columns for the marine and estuarine region and combined into one column for the other two habitat regions. An impact was recorded for any of these categories only if it was reported to result in a significant change(s) in a target population, community, or economic resource. The final column (SUM) indicates the number of impact types reported in North America.

For a-c above, data and associated references are summarized in our database (available in NEMESIS 2009). For references on impact type on each species, see Appendix 3. Note that impact references are not an exhaustive list for all species; in cases where multiple sources demonstrated the same type of impact, a subset was selected that included quantitative measures with highest levels for effect magnitude and certainty (see text and Appendices 2 and 3). Additional references are available in NEMESIS (2009) and upon request.

Taxonomic group and species	Coast	Salinity range	Impact type										Other global regions	Sum
			North America											
			Marine and estuarine							Fresh				
			P	C	X	F	H	T	E					
Cladocera														
<i>Daphnia lumholtzi</i>	A, G, P	F									F,C		0	
<i>Ilyocryptus agilis</i>	A	F											0	
Copepoda-Harpacticoida														
<i>Harpacticella paradoxa</i>	P	F											0	
Copepoda-Calanoidea														
<i>Acartiella sinensis</i>	P	B											0	
<i>Sinocalanus doerrii</i>	P	F		1		1							2	
<i>Pseudodiaptomus forbesi</i>	P	B		1		1		1					3	
<i>Pseudodiaptomus inopinus</i>	P	B											0	
<i>Pseudodiaptomus marinus</i>	P	M		1									1	
<i>Eurytemora affinis</i> (A subclade)	P	M	1			1		1					3	
<i>Tortanus dextrilobatus</i>	P	B	1										1	
Copepoda-Cyclopoida														
<i>Lernaea cyprinacea</i>	A, P	F			1						X		1	
<i>Mytilicola orientalis</i>	P	M			1							X	1	
<i>Pseudomyicola ostreae</i>	P	M											0	
<i>Limnoithona sinensis</i>	P	F											0	
<i>Limnoithona tetraspina</i>	P	B		1									1	
<i>Oithona davisae</i>	P	M											0	
Cirripedia-Rhizocephala														
<i>Loxothylacus panopaei</i>	A	M			1								1	
Cirripedia-Thoracica														
<i>Amphibalanus amphitrite</i>	A; G; P	M		1					1			C,E	2	
<i>Amphibalanus eburneus</i>	P	M							1			E	1	
<i>Amphibalanus improvisus</i>	P	B							1			C,H,E	1	
<i>Amphibalanus reticulatus</i>	A; G	M							1			E	1	
<i>Balanus trigonus</i>	A; G	M							1			E	1	
<i>Chthamalus fragilis</i>	A*	M											0	
<i>Megabalanus coccopoma</i>	A	M											0	
Ostracoda														
<i>Eusarsiella zostericola</i>	P	M											0	
<i>Aspidoconcha linnoriae</i>	P	M											0	

(continued)



Taxonomic group and species	Coast	Salinity range	Impact type												
			North America												
			Marine and estuarine							Fresh	Other global regions	Sum			
			P	C	X	F	H	T	E						
<i>Redekea californica</i>	P	M													0
<i>Spinileberis quadriaculeata</i>	P	M													0
<i>Kotoracythere inconspicua</i>	G	M													0
Leptostraca															
<i>Epinebalia</i> sp. A.	P	M													0
Mysidacea															
<i>Deltamysis holmquistae</i>	P	B													0
<i>Hyperacanthomysis longirostris</i>	P	B		1		1									2
<i>Neomysis japonica</i>	P	M													0
<i>Orientomysis aspera</i>	P	B													0
<i>Orientomysis hwanhaiensis</i>	P	M													0
<i>Praunus flexuosus</i>	A	M													0
Cumacea															
<i>Nippoleucon hinumensis</i>	P	M													0
Isopoda															
<i>Asellus hilgendorfi</i>	P	F													0
<i>Caecidotea racovitzai</i>	P	F													0
<i>Caecijaera horvathi</i>	P	M													0
<i>Dynoides dentisinus</i>	P	M													0
<i>Eurylana arcuata</i>	P	M													0
<i>Gnorimosphaeroma rayi</i>	P	M													0
<i>Iais californica</i>	P	M													0
<i>Iais floridana</i>	A; G	M													0
<i>Ianiropsis</i> sp.	A	M													0
<i>Ligia exotica</i>	A; G	M													0
<i>Ligia oceanica</i>	A	M													0
<i>Limnoria pfefferi</i>	A; G	M													0
<i>Limnoria quadripunctata</i>	P	M								1		E			1
<i>Limnoria tripunctata</i>	P (Cr)	M								1		E			1
<i>Paracerceis sculpta</i>	A	M													0
<i>Paradella diana</i>	A; G	M													0
<i>Paranthura japonica</i>	P	M													0
<i>Pseudosphaeroma campbellensis</i>	P	M													0
<i>Sphaeroma quoianum</i>	P	M					1			1					2
<i>Sphaeroma terebrans</i>	A; G	M; F					1			1					2
<i>Sphaeroma walkeri</i>	A; G; P	M													0
<i>Synidotea laevidorsalis</i>	A; P	M													0
<i>Uromunna</i> sp. A	P	B													0

(continued)

Taxonomic group and species	Coast	Salinity range	Impact type													
			North America													
			Marine and estuarine								Fresh	Other global regions	Sum			
			P	C	X	F	H	T	E							
Tanaidacea																
<i>Sinelobus cf. stanfordi</i>	P	M														0
Amphipoda-Gammaridea																
<i>Abludomelita rylovae</i>	P	M														0
<i>Ampelisca abdita</i>	P	M	1	1												2
<i>Ampithoe longimana</i>	P	M														0
<i>Ampithoe valida</i>	P	M														0
<i>Aoroides secunda</i>	P	M														0
<i>Chelura terebrans</i>	P (Cr)	M								1						1
<i>Crangonyx floridanus</i>	P	F														0
<i>Crangonyx pseudogracilis</i>	P	F											C			0
<i>Echinogammarus ischnus</i>	A	F									C		C			0
<i>Eochelidium miraculum</i>	P	M														0
<i>Eochelidium</i> sp. A	P	M														0
<i>Gammarus daiberi</i>	P	B				1										1
<i>Gammarus tigrinus</i>	A	B											C,P			0
<i>Gitanopsis</i> sp.	A	M														0
<i>Grandidierella japonica</i>	P	M														0
<i>Incisocalliope derzhavini</i>	P	M														0
<i>Jassa marmorata</i>	P	M			1											1
<i>Melita nitida</i>	P	M														0
<i>Microdeutopus gryllotalpa</i>	A; P	M	1													1
<i>Monocorophium acherusicum</i>	P (Cr)	M	1	1			1						C			3
<i>Monocorophium insidiosum</i>	P (Cr)	M														0
<i>Monocorophium uenoi</i>	P	M														0
<i>Paracorophium lucasi</i>	P	M														0
<i>Paradexamine</i> sp.	P	M														0
<i>Corophium alienense</i>	P	M														0
<i>Corophium heteroceratum</i>	P	M														0
<i>Stenothoe valida</i>	P	M														0
<i>Transorchestia enigmatica</i>	P	M														0
Amphipoda-Caprellidea																
<i>Caprella drepanochir</i>	P*	M														0
<i>Caprella mutica</i>	A; P	M											C			0
<i>Caprella scaura</i>	A; G; P	M														0
<i>Caprella simia</i>	P	M														0
Decapoda-Anomura																
<i>Petrolisthes armatus</i>	A*	M		1		1	1									3
<i>Upogebia affinis</i>	A*	M														0

(continued)

Taxonomic group and species	Coast	Salinity range	Impact type										Other global regions	Sum
			North America											
			Marine and estuarine							Fresh				
			P	C	X	F	H	T	E					
Decapoda-Astacoidea														
<i>Orconectes virilis</i>	A; P	F										C,E	0	
<i>Pacifastacus leniusculus</i>	P*	F										C,T,E	0	
<i>Procambarus clarkii</i>	A; G*; P	F										H,E	0	
Decapoda-Caridea														
<i>Exopalaemon modestus</i>	P	F		1									1	
<i>Macrobrachium olfersii</i>	A; G	C											0	
<i>Palaemon macrodactylus</i>	P	M											0	
Decapoda-Brachyura														
<i>Carcinus maenas</i>	A; P	M	1	1						1		P,C,E	3	
<i>Charybdis hellerii</i>	A; G	M											0	
<i>Eriocheir sinensis</i>	P; A	C				1	1	1				H,E	3	
<i>Eurypanopeus depressus</i>	A*	M											0	
<i>Hemigrapsus sanguineus</i>	A	M	1	1									2	
<i>Platychirograpsus spectabilis</i>	G	C											0	
<i>Rhithropanopeus harrisi</i>	P	B											0	

## Appendix 2

Classification of information type and effect magnitude for non-native species of crustaceans considered established in tidal (marine and estuarine) waters of North America. Information included is as follows:

- (a) **Taxonomic Group and Species** is provided for each crustacean classified as non-native and established in North America.
- (b) **Information Type** indicates the quality of information source that reported an impact. Information type was classified as one of the following: 1=qualitative information (including best professional judgment); 2=presence/absence data that indicate a measureable change associated with the occurrence of the non-native species; 3=mechanistic or autoecological data that infer impact has occurred; 4=correlative data that demonstrates a quantitative relationship between the invader (presence or abundance) and an effect; 5=controlled laboratory experiment(s); 6=controlled field experiment(s). Information type is shown for the same categories and format as outlined above (see Impact Type); MAX indicates the highest numerical value recorded for Information Type for North America.

(continued on page xx)













- (c) **Effect Magnitude** indicates an estimate of the reported effect size or magnitude. The magnitude was estimated from the original source(s) for each Impact Type and classified as one of the following: 0=undescribed or unassessed (in cases where a significant impact is reported); 1=an effect of <10% change; 2=an effect of 10–50% change; 3=an effect of 50–75% change; 4=an effect of >75% change. Information type is shown for the same categories and format as outlined above (see Impact Type); MAX indicates the highest numerical value recorded for Effect Magnitude for North America.

For references associated with impact characteristics of each species, see Appendix 3. Note that impact references are not an exhaustive list for all species; in cases where multiple sources demonstrated the same type of impact, a subset was selected that included quantitative measures with highest levels for effect magnitude and certainty (see text and Appendices 2 and 3). Additional references are available in NEMESIS (2009) and upon request.

### Appendix 3

Classification of certainty that observed effects were caused by the respective non-native species of crustaceans considered established in tidal (marine and estuarine) waters of North America. Information included is as follows:

- (a) **Taxonomic Group and Species** is provided for each crustacean classified as non-native and established in North America.
- (b) **Certainty** provides a qualitative and categorical index of the strength of inference about impact magnitude reported. This is derived from the information type, where certainty or confidence in available impact estimates is considered low in the absence of quantitative estimates or the ability to partition effects among multiple (confounding) factors. Values are: 1=low, 2=medium, 3=high. Information type is shown for the same categories and format as outlined above (see Impact Type); MAX indicates the highest numerical value recorded for Certainty for North America.
- (c) **Impact References** shows the source(s) of information used to generate the above information matrix. Note that impact references are not an exhaustive list for all species; in cases where multiple sources demonstrated the same type of impact, a subset was selected that included quantitative measures with highest levels for effect magnitude and certainty (see text and Appendices 2 and 3). Additional references are available in NEMESIS (2009) and upon request.



Taxonomic group & species	Certainty										Impact references (N. American marine-estuarine in bold)	
	North America							Other global regions	Max			
	Marine and estuarine						Fresh					
	P	C	X	F	H	T		E				
Cirripedia-Rhizocephala <i>Loxothylacus panopaei</i>			1								1	<b>Alvarez et al. 1995;</b> <b>Hines et al. 1997;</b> <b>Kruse and Hare 2007</b>
Cirripedia-Thoracica <i>Amphibalanus amphitrite</i>		1						1		1	1	<b>Visscher 1927;</b> <b>Moore and Frue 1959;</b> <b>Sutherland and Karlson 1977;</b> <b>Bros 1987;</b> Zvyagintsev 2003; Boudreaux et al. 2009;
<i>Amphibalanus eburneus</i>								1		1	1	<b>Visscher 1927;</b> <b>Moore and Frue 1959;</b>
<i>Amphibalanus improvisus</i>								1		1-3	1	Vuorinen et al. 1986; Zvyagintsev 2003; Dürr and Wahl 2004; Kotta et al. 2007
<i>Amphibalanus reticulatus</i>								1		1	1	Utinomi 1970; <b>Moore et al. 1974</b>
<i>Balanus trigonus</i>								1		1	1	Zevina 1988
<i>Chthamalus fragilis</i>											0	
<i>Megabalanus coccopoma</i>											0	
Ostracoda												
<i>Eusarsiella zostericola</i>											0	
<i>Aspidoconcha limnorica</i>											0	
<i>Redekea californica</i>											0	
<i>Spinileberis quadriaculeata</i>											0	
<i>Kotoracythere inconspicua</i>											0	
Leptostraca												
<i>Epinebalia</i> sp. A.											0	
Mysidacea												
<i>Deltamysis holmquistae</i>											0	
<i>Hyperacanthomysis longirostris</i>		1		1							1	<b>Feyrer et al. 2003;</b> <b>Nobriga and Feyrer 2008</b>
<i>Neomysis japonica</i>											0	
<i>Orientomysis aspera</i>											0	<b>Nobriga and Feyrer 2008</b>

(continued)

Taxonomic group & species	Certainty										Impact references (N. American marine-estuarine in bold)	
	North America							Other global regions	Max			
	Marine and estuarine						Fresh					
	P	C	X	F	H	T		E				
<i>Orientomysis hwanhaiensis</i>											0	
<i>Praunus flexuosus</i>											0	
Cumacea												
<i>Nippoleucon hinumensis</i>											0	
Isopoda												
<i>Asellus hilgendorfi</i>											0	
<i>Caecidotea racovitzai</i>											0	
<i>Caecijaera horvathi</i>											0	
<i>Dynoides dentisinus</i>											0	
<i>Eurylana arcuata</i>											0	
<i>Gnorimosphaeroma rayi</i>											0	
<i>Iais californica</i>											0	
<i>Iais floridana</i>											0	
<i>Ianiropsis</i> sp.											0	
<i>Ligia exotica</i>											0	
<i>Ligia oceanica</i>											0	
<i>Limnoria pfefferi</i>											0	
<i>Limnoria quadripunctata</i>							3		3	3	3	Eltringham and Hockley 1967; Coughlan 1977; <b>Carlton 1979</b> ; <b>Cohen and Carlton 1995</b>
<i>Limnoria tripunctata</i>							3		3	3	3	Eltringham and Hockley 1967; Coughlan 1977; <b>Carlton 1979</b> ; <b>Quayle 1992</b> ; <b>Cohen and Carlton 1995</b>
<i>Paracerceis sculpta</i>											0	
<i>Paradella diana</i>											0	
<i>Paranthura japonica</i>											0	
<i>Pseudosphaeroma campbellensis</i>											0	
<i>Sphaeroma quoianum</i>					3		3				3	<b>Talley et al. 2001</b> ; <b>Higgins (cited by Davidson 2006)</b> ; <b>Davidson 2006</b>
<i>Sphaeroma terebrans</i>					1		1				1	<b>Rehm and Humm 1973</b> ; <b>Conover and Reid 1975</b> ; <b>Simberloff et al. 1978</b> ; <b>Ribi 1982</b> ; <b>Villalobos 1985</b> ; <b>Estevez 1994</b>
<i>Sphaeroma walkeri</i>											0	

(continued)

Taxonomic group & species	Certainty										Impact references (N. American marine-estuarine in bold)	
	North America								Other global regions	Max		
	Marine and estuarine							Fresh				
	P	C	X	F	H	T	E					
<i>Synidotea laevidorsalis</i>											0	
<i>Uromunna</i> sp. A											0	
Tanaidacea												
<i>Sinelobus</i> cf. <i>stanfordi</i>											0	
Amphipoda-Gammaridea												
<i>Abludomelita rylovae</i>											0	
<i>Ampelisca abdita</i>	1	1									1	<b>Nichols and Thompson 1985</b>
<i>Ampithoe longimana</i>											0	
<i>Ampithoe valida</i>											0	
<i>Aoroides secunda</i>											0	
<i>Chelura terebrans</i>								1			1	<b>Barnard 1950; Barnard 1955; Wallour 1960; Kuhne and Becker 1964</b>
<i>Crangonyx floridanus</i>											0	
<i>Crangonyx</i> <i>pseudogracilis</i>									1		0	
<i>Echinogammarus</i> <i>ischnus</i>									3		0	
<i>EOchelidium miraculum</i>											0	
<i>EOchelidium</i> sp. A											0	
<i>Gammarus daiberi</i>				1							1	<b>Nobriga and Feyrer 2008; Grimaldo et al. 2009</b>
<i>Gammarus tigrinus</i>									3		0	<b>Van Riel et al. 2007</b>
<i>Gitanopsis</i> sp.											0	
<i>Grandidierella</i> <i>japonica</i>											0	<b>West et al. 2003; Whitcraft et al. 2008</b>
<i>Incisocalliope derzhavini</i>											0	
<i>Jassa marmorata</i>		1									1	
<i>Melita nitida</i>											0	
<i>Microdeutopus</i> <i>gryllotalpa</i>	3										3	<b>Hauxwell et al. 1998</b>
<i>Monocorophium</i> <i>acherusicum</i>	1	1			1				1		1	<b>Barnard 1958; Onbe 1966; Talman et al. 1999</b>
<i>Monocorophium</i> <i>insidiosum</i>											0	
<i>Monocorophium uenoi</i>											0	
<i>Paracorophium lucasi</i>											0	
<i>Paradexamine</i> sp.											0	
<i>Corophium alienense</i>											0	
<i>Corophium</i> <i>heteroceratum</i>											0	

(continued)

Taxonomic group & species	Certainty									Impact references (N. American marine-estuarine in bold)		
	North America							Other global regions	Max			
	Marine and estuarine						Fresh					
	P	C	X	F	H	T		E				
<i>Stenothoe valida</i>										0		
<i>Transorchestia enigmatica</i>										0		
Amphipoda-Caprellidea												
<i>Caprella drepanochir</i>									2	0	<b>Page et al. 2007;</b> Shucksmith et al. 2009	
<i>Caprella mutica</i>										0		
<i>Caprella scaura</i>										0		
<i>Caprella simia</i>										0		
Decapoda-Anomura												
<i>Petrolisthes armatus</i>			3		3	3				3	<b>Hollebone and Hay 2008</b>	
<i>Upogebia affinis</i>										0		
Decapoda-Astacoidea												
<i>Orconectes virilis</i>									1	0	Schwartz et al. 1963	
<i>Pacifastacus leniusculus</i>									1	0	Cohen and Carlton 1995; Taugbøl and Johnsen 2006	
<i>Procambarus clarkii</i>									1	0	Cohen and Carlton 1995	
Decapoda-Caridea												
<i>Exopalaemon modestus</i>			1							1	<b>Hieb 2006; Nobriga and Feyrer 2008</b>	
<i>Macrobrachium olfersii</i>										0		
<i>Palaemon macrodactylus</i>										0		
Decapoda-Brachyura												
<i>Carcinus maenas</i>	3	2							2	1-3	3	<b>Vermeij 1982;</b> <b>Grosholz et al.</b> 2000; <b>Jensen et al.</b> 2002; Walton et al. 2002; <b>Trussell et al.</b> 2004; <b>Floyd and</b> <b>Williams 2004;</b> <b>Griffen and Byers</b> 2006; <b>Grosholz et al</b> (in review)
<i>Charybdis hellerii</i>											0	
<i>Eriocheir sinensis</i>					1	1	3			1-3	3	Panning 1939; <b>Rudnick et al.</b> 2003; <b>Chinese</b> <b>mitten crab</b> <b>Working Group</b> 2003; <b>Rudnick</b> <b>et al. 2005</b>
<i>Eurypanopeus depressus</i>											0	

(continued)

Taxonomic group & species	Certainty										Impact references (N. American marine-estuarine in bold)	
	North America							Other global regions	Max			
	Marine and estuarine											
	P	C	X	F	H	T	E	Fresh				
<i>Hemigrapsus sanguineus</i>	3	3									3	<b>Jensen et al. 2002; Lohrer and Whitlatch 2002; Griffen and Byers 2006; Tyrrell et al. 2006; Griffen and Delaney 2007; Griffen et al. 2008</b>
<i>Platychirograpsus spectabilis</i>											0	
<i>Rhithropanopeus harrisi</i>											0	<b>Cohen and Carlton 1995; Zaitsev and Öztürk 2001, cited by Roche and Torchin 2007</b>

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