No Frontiers in the Sea for Marine Invaders and their Parasites?

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Prepared for BNZ Pre-clearance Directorate
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Executive Summary

This report describes the results of a study investigating the geographic distribution of two non-indigenous crabs, *Romaleon gibbosulum* and *Glebocarcinus amphioetus* (Decapoda: Cancridae), in the North and South Island of New Zealand. In addition, we investigated their size distribution, habitats and parasite fauna in their Japanese native range. The parasite fauna of the New Zealand native crab *Metacarcinus novaezelandiae* (Decapoda: Cancridae) was also investigated to assess whether they have parasites that might potentially infect the two non-indigenous cancrid crabs and therefore could be used for controlling invader populations. Finally, we reviewed the diversity and occurrence of non-indigenous crabs (Brachyura) worldwide to identify patterns in their invasion biology.

To determine the distribution and relative abundance of the two non-indigenous cancrid crabs identified during MAFBNZ port surveys, a variety of methods were used to sample a large range of habitats in areas where these species were previously detected (Gisborne, Wellington, Lyttelton, Timaru and Bluff), as well as at several pristine sites on the Banks Peninsula. Despite intensive sampling effort from February 2005 to March 2007, no further *R. gibbosulum* or *G. amphioetus* were found in New Zealand. The apparently transient occurrence of these exotic crab species is somewhat surprising considering the wide regional distribution (North and South Islands) and temporal extent of the original first records (*R. gibbosulum* in November 2001 and *G. amphioetus* in January 2003). Explanations for the current apparent absence of the exotic cancrid species could either be due to a) small 'starter' populations that were too small to establish a self-sustaining population, b) environmental conditions that are not compatible in the long-term to support these species, c) changes in propagule pressure (i.e. decrease), or d) a very small population still in the lag phase of its establishment and having a low probability of being sampled. Overall, the New Zealand environment appears to have similar habitats to the ones reported from the crabs' native range in Japan, and therefore New Zealand could well provide suitable habitat for these crab species in the future.

The parasite fauna of *G. amphioetus* and *R. gibbosulum* was investigated in their native habitat in Japan in July and August 2006 using fresh and preserved material from over 20 locations, but primarily from Ise Bay and Osaka Bay (Honshu). A total of 160 specimens were examined: 149 *R. gibbosulum* and 11 *G. amphioetus*. The size ranges of the specimens suggest that the original New Zealand records of the two taxa included mature adults (*R. gibbosulum)*, and individuals probably nearing maturity (*G. amphioetus*), indicating that both taxa could have potentially bred. All crabs were examined externally and some internally for the presence of parasites or symbionts, however none were found. Depth distribution and habitat use in Japan demonstrate that these two Asian cancrid species occupy in part a very similar habitat to that of the New Zealand endemic cancrid crab *M. novaezelandiae*, and the common grapsid crabs *Hemigrapsus crenulatus* and *Hemigrapsus sexdentatus*, which occur in the rocky to sandy, shelly intertidal and subtidal in New Zealand. The parasite fauna of the non-indigenous Asian cancrid crabs in New Zealand was not investigated as none of the species were found during this project.

The parasite fauna of the endemic crab *M. novaezelandiae* was investigated to evaluate whether native parasites are present that could potentially increase the biological resistance against the spread of the non-indigenous cancrid crabs. Two exciting discoveries were made: a castrating parasite (a barnacle) on *M. novaezelandiae* and an egg predator (a ribbon worm) on the red rock crab *Plagusia chabrus* (Plagusiidae). None of these families were previously

known from New Zealand and are likely endemics. Most (93.5% of 1118) cancrid crabs in Wellington were infected by the rhizocephalan barnacle parasite (*Heterosaccus* sp.). Surprisingly, this rhizocephalan has so far not been found anywhere else in New Zealand even though 2528 crabs were collected from other sites. The reproductive cycle of the rhizocephalan in Wellington appears to be continuous throughout the year with a slight peak of newly emerging externas in early summer. Cancrid crabs from our other collection sites have a range of minor external epibionts, but overall the populations appear to be in a very healthy state in regards to any pathology except in Wellington. The ribbon worm was found in several locations on the North and South Island from collections made during the exotic crab surveys, and from Te Papa museum specimens. The discoveries of a new rhizocephalan parasite and a nemertean egg predator are important for our understanding of the population dynamics of native and exotic New Zealand crabs. For example, the localised occurrence of these new species indicates that some crab populations are fairly isolated. Moreover, these newfound species might play an important role in the biotic resistance of New Zealand's marine environment by lowering densities of non-indigenous crabs. Comparative genetic work has been carried out on the New Zealand *Heterosaccus* sp. and it was shown that the New Zealand species was significantly different from the other species tested and most closely related to the European species *Sacculina carcini*, which infects among others the European shore crab *Carcinus maenas*. The New Zealand *Heterosaccus* might provide the first line of defence should *C. maenas* arrive in the country.

Literature reviews revealed 57 non-indigenous brachyuran decapods in 25 families, of which 32 species (57.1%) have become established. Three brachyuran superfamilies stand out in their high number of recorded non-indigenous species: Portunoidea (swimming crabs), Grapsoidea (shore crabs) and Majioidea (spider crabs), with fifteen, eight and seven species, respectively. Xanthoidea (mud crabs) are remarkable as all five of their recorded non-indigenous species have also become established. The Cancroidea include in total six species which have been recorded outside their native range, but so far only one has become established. The families Portunidae (swimming crabs), Varunidae ('grapsid crabs') and Leucosiidae (pebble crabs) are the families with the highest number of established exotic species, with ten, four and three, respectively. The Mediterranean Sea has the highest number of non-indigenous brachyuran species (42, with 19 established) as many have invaded through the Suez Canal. In New Zealand four brachyuran species have been recorded (*Pyromaia tuberculata, Charybdis japonica, G. amphioetus* and *R. gibbosulum*), of which *P. tuberculata* and *C. japonica* have become established. In Australia, three brachyuran species have been recorded and these have also become established (*P. tuberculata, M. novaezelandiae, C. maenas*). Non-indigenous brachyuran crabs are a serious issue in many parts of the world (unless they are commercially fished) as they often establish high population densities and tend to compete with local fauna for food and shelter. Although the total number of non-indigenous brachyuran crabs is smaller compared to other major taxa (e.g., Mollusca), their impact can be substantial. Consequently, preventative measures are important as well as developing better control techniques to limit their impacts.

General background for project

Baseline surveys of New Zealand's ports and harbours carried out for the Ministry of Agriculture and Forestry – Biosecurity New Zealand (MAFBNZ) by the National Institute of Water and Atmospheric Research (NIWA) have discovered several non-indigenous crab species that were not previously known from New Zealand waters (e.g., Inglis *et al.* 2005, 2006a, b, c, d). This project was to follow up on the original baseline survey detections of two non-indigenous crab species, *Glebocarcinus amphioetus* and *Romaleon gibbosulum* (Decapoda: Cancridae), taxa for which basic aspects of biology and life history are poorly known (Inglis 2005, 2006a, b, c, d). This research had four specific objectives:

1) **Survey five ports in New Zealand to determine whether *G. amphioetus* and *R. gibbosulum* were still present, and investigate their potential impact on local flora and fauna.**

Five specimens of *R. gibbosulum* were found in the ports of Lyttelton, Wellington and Timaru from scrapings off wharf piles in November 2001, and four specimens of *G. amphioetus* were discovered from Bluff and Gisborne from scrapings off wharf piles in January 2003. More information was needed to assess the population status, habitat requirements and potential impacts of these two species in New Zealand.

2) **Investigate the size distribution, habitat, and parasite fauna of *G. amphioetus* and *R. gibbosulum* from their native habitat in Japan.**

Marine invasive species may in part be successful invaders because their natural enemies, such as parasites and diseases, are not present in areas outside of their native range (Torchin *et al.* 2003). Determining the habitat use, population structure and parasites of *G. amphioetus* and *R. gibbosulum* in their native range (Japan) provides a context against which findings from New Zealand can be compared, informing estimates of the impacts these species may have on the New Zealand marine environment.

3) **Investigate the parasite fauna of the New Zealand endemic crab *Metacarcinus novaezelandiae* to explore the extent of biological resistance that non-indigenous crabs might encounter.**

Exotic cancrid crabs could potentially be affected by the parasite fauna of the endemic crab *Metacarcinus novaezelandiae*. Therefore, characterising these parasites can provide insights towards the degree of biotic resistance that non-indigenous crabs may encounter in New Zealand [biological control agents]

4) **Provide an overview of non-indigenous brachyuran decapods worldwide.**

Some brachyuran species are well known for being invasive, such as the European green crab *Carcinus maenas* (Klassen & Locke 2007) and the Chinese mitten crab *Eriocheir sinensis* (Veilleux & de Lafontaine 2007), but less tends to be known about other non-indigenous brachyuran crabs. A literature review of current developments in the field of brachyuran invasion biology will provide a topical summary of key species, invasion trends, and distributional patterns.

Part 1. Survey of five ports for the two non-indigenous crabs *Glebocarcinus amphioetus* and *Romaleon gibbosulum* (Crustacea: Cancridae) in New Zealand

1.1 ABSTRACT

Brachyuran introductions play a significant part in global marine invasions with some of them ranked among the 100 worst alien invasive species. A few specimens of two exotic brachyuran species (*Romaleon gibbosulum* and *Glebocarcinus amphioetus*) were discovered in 2001 and 2003 in New Zealand waters, but the extent of their distribution, densities and impact on native flora and fauna were unknown. Therefore, to determine the distribution and relative abundance of these two Asian non-indigenous cancrid crabs in New Zealand, a variety of habitats were sampled using a range of methods at sites from which the species were previously known: Gisborne, Wellington, Lyttelton, Timaru and Bluff, as well as several pristine sites on the Banks Peninsula. Despite intensive sampling effort from February 2005 to March 2007, neither *R. gibbosulum* nor *G. amphioetus* were found. The apparently transient occurrence of these exotic crab species is somewhat surprising considering the wide regional distribution (North and South Islands) and temporal extent (*R. gibbosulum* in November 2001 and *G. amphioetus* in March 2003) of the original first records. Explanations for the current apparent absence of the exotic cancrid species could either be due to a) small 'starter' populations that were too small to maintain themselves, b) environmental conditions that are not compatible in the long term for these species, c) changes in propagule pressure (i.e. decrease), or d) a very small population still in the lag phase of its establishment and having a low probability of being sampled. Overall, the New Zealand environment appears to have similar habitats to those reported from the native range, and New Zealand therefore could provide suitable habitat for these crab species in the future.

1.2 INTRODUCTION

Brachyuran introductions play a significant part in global marine invasion issues with some of them ranked among the 100 worst alien invasive species (Lowe *et al.* 2000). A total of 57 non-indigenous Brachyura are recorded worldwide (see Part 4) and several have been shown to significantly change the biotic interaction in their new range. The European shore crab *Carcinus maenas*, for example, has been considered to be an "ecosystem engineer" (Crooks 2002), as it has the ability to modify entire ecosystem through predation, competition and habitat modification (Grosholz & Ruiz 1996). Another brachyuran example that has successfully spread is the Asian shore crab *Hemigrapsus sanguineus*. It has a broad diet and occupies habitats similar to native crab species. It has a significant ecological impact by disrupting food webs in their introduced range (Gerard *et al.* 1999). Other examples of potential effects of non-native crabs include habitat alteration through intensive burrowing behaviour (*Eriocheir sinensis*; Veilleux & De Lafontaine 2007) and introduction of diseases (white spot baculovirus in the case of *Rhithropanopeus harisii*; Payen & Bonami 1979).

Baseline surveys of New Zealand's ports and harbours carried by the Ministry of Agriculture and Forestry – Biosecurity New Zealand (MAFBNZ) recorded for the first time the Asian non-indigenous crabs, *Romaleon gibbosulum* and *Glebocarcinus amphioetus* (Decapoda: Cancridae), in New Zealand waters (Inglis *et al.* 2005, 2006a, b, c, d). Five specimens of *R. gibbosulum* were found in scrapings off wharf piles from the ports of Lyttelton, Wellington

and Timaru in November 2001. *R. gibbosulum* females ranged in size between 10.7–14.4 mm carapace width, and males between 7–23.5 mm. Four specimens of *G. amphioetus* were discovered in wharf pile scrapings from Bluff and Gisborne in January 2003. *G. amphioetus* females ranged in size between 7–23.5 mm carapace width and the male was 21.8 mm. No ovigerous crabs were collected in New Zealand. Very limited information was available on basic biology and life history aspects of these Asian crab species.

It was therefore seen as important to determine the population status of the new arrivals in New Zealand to be able to assess the potential impact and possible management options. Knowledge on the population status would enable us to estimate potential impacts on issues such as New Zealand's biodiversity, native habitat structures, protected areas, protected species, trophic interactions, aquaculture or vessels/moorings.

The aim of this project was therefore to investigate the current state of invasion of the two non-indigenous crabs *Glebocarcinus amphioetus* and *Romaleon gibbosulum* in five ports and some pristine areas to determine the distribution, abundance and, if the crabs are detected, their ecological impacts in New Zealand waters.

1.3 METHODS

The sampling effort was primarily targeted towards the previously known locations of *R. gibbosulum* and *G. amphioetus* in ports and harbours in New Zealand to maximise the chance of detecting them. In addition, some more pristine areas were included for comparison. Detailed information was collected on cancrid crabs (see below) and notes were taken on the presence of other larger crustaceans (i.e. typically their generic association) encountered during the sampling.

1.3.1 **Collection sites**: In the first year (2005), we concentrated our surveys on Lyttelton Harbour and port Timaru and also included some more pristine areas around Banks Peninsula (Pigeon Bay, Les Bons Bay, Taylor's Mistake, Akaroa). In the second and third years (2006 and 2007), we also surveyed the ports of Gisborne, Bluff and Wellington (Table 1.1). More sampling effort was undertaken in Wellington in the second year because of the discovery of the parasitic barnacle *Heterosaccus* sp.

Table 1.1. General region and specific sites of sampling effort.

GENERAL LOCATION	SPECIFIC SITES
Lyttelton Harbour	
Port	Cashin quay, Z berth, Gladstone pier, tug jetties, wharves 2-7, cattle jetty, oil wharf, public fishing jetty
New Marina	slipway and inner marina
Inner Harbour	around Quail Island, around shag reef, Charteris Bay
Diamond Harbour	main wharf
Banks Peninsula	
Taylors Mistake Bay	southern shore line
Le Bons Bay	outer shores
Pigeon Bay	outer shores
Akaroa	inner harbour
Port Levy	outer shores
Pegasus Bay	
Scarborough	near slipway
Timaru	
Port	outer North mole, fishermans wharf, inner North mole, wharves 1-3, commercial slipway
Caroline Bay	along northern shore line
Gisborne	
Port	marina, berths 6-8, diversion wall, Butlers wall, breakwater wall, slipway
Outer 'Port'	extension of breakwater wall
Bluff	
Port	island harbour bridge, berth 1-8
Town wharf	bridge, wharves 11-14
Fisherman wharf	outer and inner wharves
Wellington	
Port	Aotea quay 1-6, Thorndon breakwater, Seaview wharf, Burnham wharf,
Evans Bay	jetty Greta point, inner and outer bay
South Shore, Island Bay	along rocky shore
Inner Harbour	around island, along Petone and Seaview

1.3.2 **Collection dates**: Lyttelton Harbour collections were carried out between Feb. 2005 and Oct. 2006. Banks Peninsula sites were sampled between Feb. 2005 and Nov. 2006; Timaru between Mar. 2005 and Feb. 2006; Gisborne in Mar. 2006; Bluff in Apr. 2006; and Wellington between May 2006 and March 2007. An overview on sampling dates is provided in Table 1.2. and details in Appendix 1.

Table 1.2. Summary of cancrid crab surveys carried out from February 2005 to March 2007: collection dates, methods and number of endemic crab *Metacarcinus novaezelandiae* sampled.

Location	Months surveyed	Baited crab traps set	Pylons scraped	Dredge hauls taken	Crab shelters sampled	*Metacarcinus novaezelandiae (endemic)*
Lyttelton Harbour						**392**
Port	Mar, Aug, Dec 2005; Feb, May 2006	139	30	-	-	173
New Marina	Mar, Apr, Oct, Nov, Dec. 2005; Jan, Feb, Mar, May, Oct 2006	42	100	-	78	164
Inner Harbour	Feb, Mar, Jun, Oct 2005; Jan 2006	14	-	38	-	45
Diamond Harbour	Mar, Oct 2005; Jan, Apr 2006,	-	45	-	-	10
Banks Peninsula						**493**
Taylors Mistake	Feb, Mar, Apr, May, Jun 2005	26	-	-	23	286
Le Bons Bay	Feb, May, Aug 2005	-	-	-	9	29
Pigeon Bay	Feb, Mar, Apr, May, Jun, Jul 2005	24	-	-	14	62
Akaroa	Feb, Mar, Apr, May 2005; Nov 2006	30	-	-	14	16
Port Levy	Oct 2006	23	-	-	-	100
Pegasus Bay						**234**
Scarborough	Aug 2006	20	-	-	-	234
Timaru						**1368**
Port	Mar, Sep 2005; Feb 2006	72	50	-	-	134
Caroline Bay	Jun, Sep 2005	38	-	-	-	1234
Gisborne						**42**
Port	Mar 2006	101	20	-	-	42
Outer 'Port"	Mar 2006	3	-	-	-	0
Bluff						**3**
Port	Apr 2006	103	20	-	-	3

Continued **Table 1.2. Summary of cancrid crab surveys carried out from February 2005 to March 2007: collection dates, methods and number of endemic crab *Metacarcinus novaezelandiae* sampled.**

Location	Months surveyed	Baited crab traps set	Pylons scraped	Dredge hauls taken	Crab shelters sampled	*Metacarcinus novaezelandiae (endemic)*
Wellington						**1118**
Port	May, Sept 2006	61	40	-	-	8
Seaview Wharf	May, Sept, Nov, Dec 2006, Feb, Mar 2007	208	-	8	-	683
Burnham Wharf	May, Sept, Nov, Dec 2006, Feb, Mar 2007	209	40	1	-	421
Greta Point	Sep 2006	7	-	-	-	3
Island Bay, South Shore	Sep 2006	31	-	-	-	1
Evans Bay	Sep 2006	-	-	4	-	2
Shelly Bay	Sep 2007	-	-	4	-	0
TOTAL		**1151**	**345**	**55**	**138**	**3650**

1.3.3 **Collection methods**: Following collection techniques were used:

Baited crab traps: opera-house traps (Fig. 1.1a) (1.2 m long x 0.8 m wide x 0.6 m high; covered in 1 cm^2 fine mesh with two tunnel entrances at either side leading to a 14 cm wide opening) were set on the ground overnight (12–24 hours); Gee's minnow traps (Fig. 1.1b)(42 cm long, 23 cm wide, entrance funnel at either side leading to a 5 cm entrance hole, constructed out of 6.4 mm square wire mesh) were set on the ground overnight (12–24 hours); circular hoop traps (100 cm upper ring and 50 cm bottom ring connected with 50 mm mesh forming a bucket when lifted) were set flat on the ground for 1–2 hours. Fish frames of tarakihi (*Cheilodactylus macropterus*) were mostly used as bait, but in a few occasions blue cod (*Parapercis colias*), dogfish (*Squalus acanthias*), gurnard (*Curupiscis kumu*) and salmon (*Oncorhynchus tschawytscha*) were also used. All cancrid crabs collected were taken to the laboratory. The gender of all crabs was recorded and measurements were taken of the carapace width using digital callipers to the nearest 0.1 mm. The reproductive stage of the females was determined by assessing whether females were either ovigerous or not.
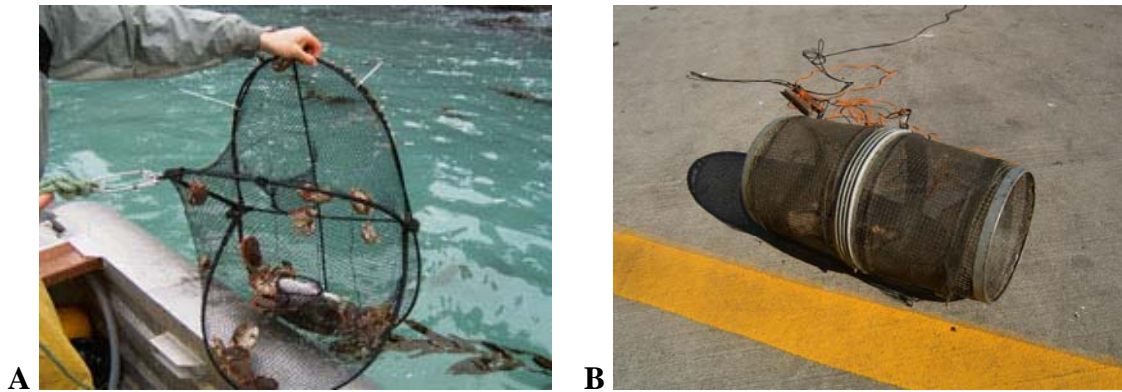
Figure 1.1. Crab traps used for collecting cancrid crabs. A. Opera house trap. B. Gee's minnow trap.

Wharf pylon scrapings: at each wharf pylon sampled, a quadrat (25 cm x 25 cm) was placed at 1 and 3 m depths by a diver. All fouling organisms were scraped off within the quadrat and collected in a 1 mm mesh collection bag. Each quadrat sample was transferred into a plastic container and taken to the laboratory where they were examined for cancrid crabs. Visual searches of seafloor were also carried out between the sampled and the surrounding pylons.

Dredging: sleds with mesh (Fig. 1.2) (entrance width approx. 1 m) were towed slowly (up to 2 knots) for approximately 100 m across the seafloor at a depths between 3 m to 20 m. The samples were washed and examined for cancrid crabs on board of the ship. All cancrid crabs collected were taken to the laboratory where the gender of the crabs was recorded and measurements were taken of the carapace width using digital callipers to the nearest 0.1 mm. The reproductive stage of the females was determined by assessing whether females were either ovigerous or not.

Figure 1.2. Benthic sleds used for cancrid crab collection.

Crab shelters: plastic mesh shelters (Fig. 1.3) of an outer mesh (2.5 cm grid) filled with randomly folded plastic mesh (5 - 7 cm grid) in the inside. We used two sizes: large cylindrical (1 m long and 0.35 m diameter known as "SMURFs" (standard monitoring units for recruitment of fish (Ammann 2004) attached to mooring lines and small cushion-like (0.3 cm wide x 0.3 cm long x 0.15 high) attached to wharf pylons. Shelters were checked after 1-4 weeks by enclosing the shelter in a bag in the water and then lifting it onto the boat for rinsing with water to remove all the animals hiding within. Each sample was placed into a plastic container and examined in the laboratory for cancrid crabs. Shelters were returned to the laboratory on the last sampling day, thoroughly washed and taken apart for final inspections.

Figure 1.3. Crab shelters (SMURFs) used for collecting cancrid crabs.

Visual searches: about 500 m shore line was searched for cancrid crabs at the low tide mark (about 20 m swath width) under rocks and kelp at each location once in the first sampling month.
An overview on trapping effort at each location is provided in Table 1.2. and details in Appendix 1.

1.4 RESULTS

Despite intensive sampling effort over two years (2. 2005 – 3. 2007) using a range of methods over a large geographic range (Table 1.2) no exotic cancrid crabs were found in the five ports nor any other locations surveyed although previously reported from some. Many of our collection sites in the ports were within 50 metres of the previously recorded locations and although we used the same methods none were detected.

However, our sampling methods were highly effective in collecting several native crustaceans, in particular the endemic cancrid crab *Metacarcinus novaezelandiae*, which appears to occupy a similar habitat to the introduced crabs (see details discussion below). Detailed notes of the collection of *M. novaezelandiae* were taken because we were examining their parasite fauna as part of our third objective investigating the biological resistance the exotic crabs would experience in New Zealand (see Part 3).

In total 3650 endemic cancrid crab, *Metacarcinus novaezelandiae,* were collected from various locations on the North and South Island of New Zealand between February 2005 and March 2007 (Table 1.2).

Metacarcinus novaezelandiae ranged in size from 3.5 to 136.0 mm carapace width (CW). The size distributions of crabs from the main locations are shown in Figures 1.2 and 1.3. The majority of crabs were of medium to large size (40–80 mm CW), but size distribution varied among the locations. For example, Lyttelton had mostly crabs larger than 80 mm CW, whereas in Timaru the majority was between 50–69 mm CW and in Wellington between 40–59 mm CW. Overall, very few ovigerous females were collected (n = 10, 0.27%); these ranged in size from 51.9 to 98.2 mm CW and were found in the four months from July to October. Large crabs were primarily sampled by baited crab traps and juvenile crabs were typically found in crab shelters or on wharf pylons. Shore surveys did not detect cancrid crabs except in one occasion when a crab was found under boulders at Taylor's Mistake.

Figure 1.1. Size distribution of male and female crab *Metacarcinus novaezelandiae* collected in Wellington.

A.

Gisborne (n = 42)

(bar chart: number of crabs vs. carapace width (mm); legend: males (n = 29), females (n = 13))

B.

Lyttelton (n = 344)

(bar chart: number of crabs vs. carapace width (mm); legend: males (n = 271), females (n = 73))

C.

Timaru (n = 1368)

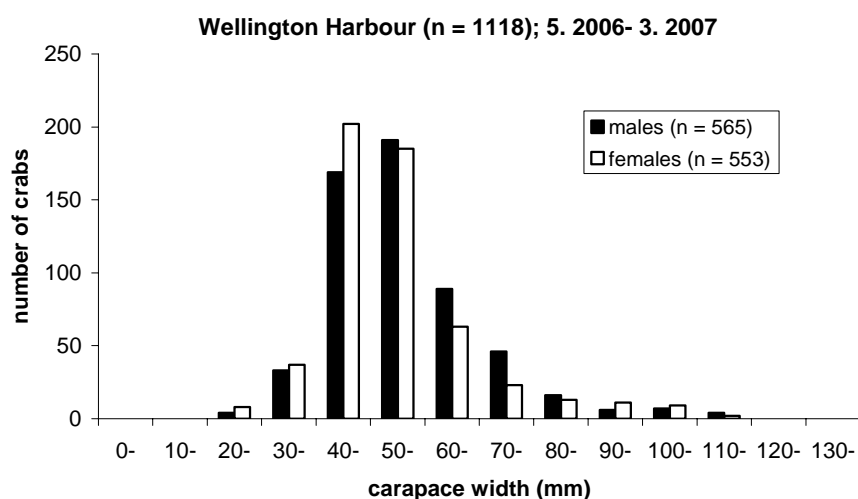*(bar chart: number of crabs vs. carapace width (mm); legend: males (n = 554), females (n = 814))*
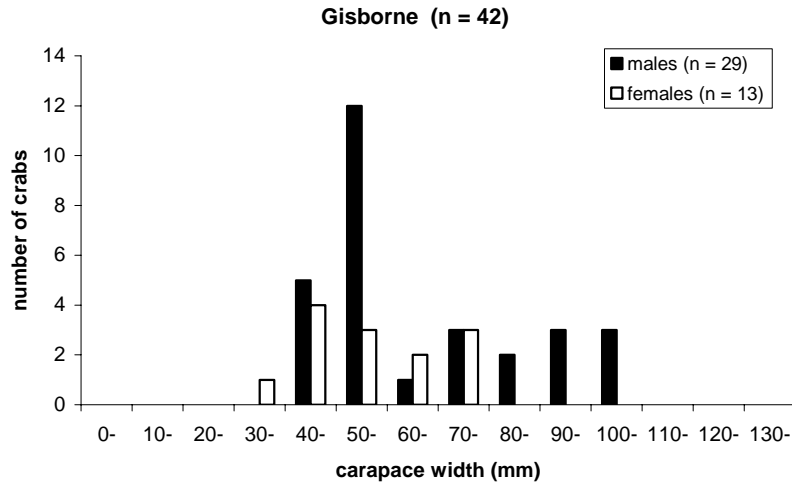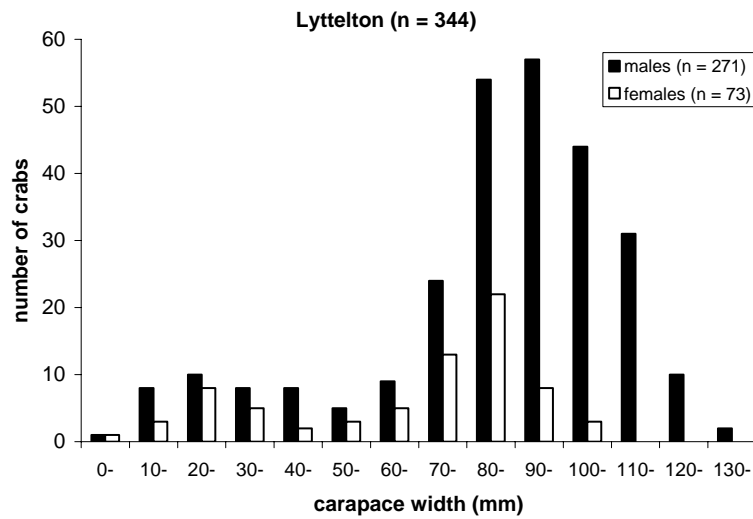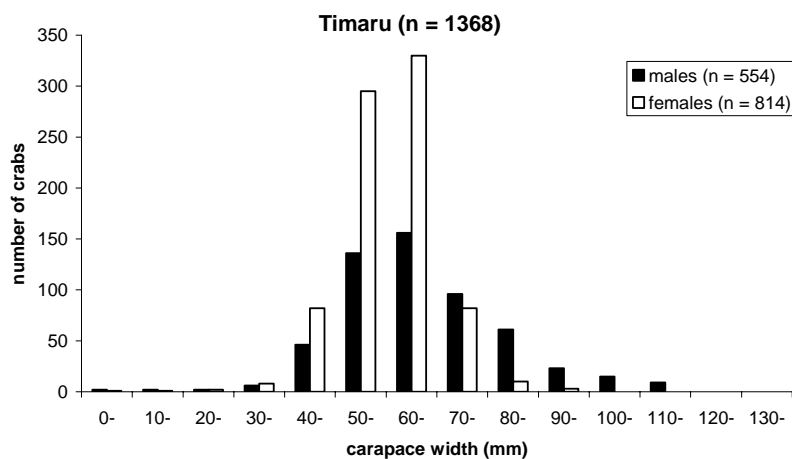
Figure 1.2. Size distribution of male and female crab *Metacarcinus novaezelandiae* collected in Gisborne (A), Lyttelton (B) and Timaru (C).

Table 1.3. Other crustaceans encountered during cancrid crab surveys. Note: these are anecdotal observations on selected groups and not a complete list of all crustaceans encountered.

Crustacea (sorted taxonomically)	Common name	Location						Collection method
		Lyttelton	Banks Peninsula	Timaru	Gisborne	Bluff	Wellington	
Stomatopoda	Mantis shrimps	-	-	-	-	-	+	D
Jasus edwardsii (Palinuridae)	Rock lobster	+	-	+	+++	+++	+	T
Paguridae	Hermit crabs	++	-	-	-	++	+++	T, D
Petrolisthes elongatus (Porcellanidae)	False crabs	++	++	+	-	-	++	T, PS
Halicarcinus spp. (Hymenosomatidae)	Pill-box crabs	++	++	-	-	-	++	CS, PS
Notomithrax spp. (Majidae)	Masking crabs	++	++	+	-	++	+++	T, D
Eurynolambrus australis (Majidae)	Triangle crab	+	++	-	-	+	+	T
Pilumnus spp. (Pilumnidae)	Hairy crab	++	++	-	-	-	++	PS
Nectocarcinus antarcticus (Portunidae)	Hairy red swimming crab	-	++	-	-	+++	++	T
Ovalipes catharus (Portunidae)	Paddle crab	++	++	+	-	-	-	T, D
Plagusia chabrus (Plagusiidae)	Red rock crab	-	+	-	++	-	-	T
Hemigrapsus crenulatus (Varuninae)	Hairy-handed crab	++	-	-	-	-	++	T, D
Macrophthalmus hirtipes (Macrophthalmidae)	Tunnelling mud crab	++	-	+	-	-	++	T, D

-, not observed; +, rarely observed (in up to 5% of traps); ++, sometimes observed (in 5-10% of traps); +++, regularly observed (in more than 10% of traps); D, benthic sled; T, baited crab traps; CS, crab shelters; PS, pylon scrapings.

Other crustaceans encountered

Although the focus of this study was on cancrid crabs notes were also taken on the presence of other larger crustaceans (i.e. typically their generic association). These included Stomatopoda, crayfish *Jasus edwardsii*, hermit crabs, false crabs, masking crabs, triangle crabs, pill box crabs, hairy crabs, tunnelling mud crabs, swimming crabs, and shore crabs (Table 1.3).

1.5 DISCUSSION

The lack of detection of the target species during our surveys was somewhat unexpected. Neither the exotic crab *R. gibbosulum* nor *G. amphioetus* were found during our surveys, despite intensive and targeted sampling. The apparently transient occurrence of these exotic crab species is somewhat surprising considering the wide regional distribution (North and South Islands) and temporal extent (November 2001 and March 2003) of the original records in New Zealand.

It is known from other non-indigenous species that many arrive but do not become established. As a rule of thumb it has been proposed that 10% of introduced species will settle and 1% will become invasive in the terrestrial environment (Williamson & Fitter 1996). However, more seem to become establish in the marine environment where 55% (456 of 828 species) have become established in the combined 'European Seas' (Streftaris *et al.* 2005) and 52% (385 of 745) in the Mediterranean (Zenetos *et al.* 2005).

One of the important factors determining establishment success is temperature. The global distribution patterns of exotic *Carcinus maenas* and *C. aestuarii* appears to be primarily regulated by temperature. They have become established in Atlantic North America, Australia, South Africa, Japan and Pacific North America, but not in the tropical regions were one-off collections were made (e.g. Hawaiian Islands, Sri Lanka, Madagascar) (Carlton & Cohen 2003).

In Osaka Bay, where *R. gibbosulum* and *G. amphioetus* occur, surface temperatures range from 6 – 19°C and bottom temperatures from 6 – 18°C. Coastal water can warm up to 32°C in some locations (Miyadi 1940). This indicates that both cancrid species are adapted to a wide range of temperatures. The recorded ranges for surface and bottom temperatures of Osaka Bay are within the range of the mean monthly temperatures recorded for New Zealand harbours (e.g. Bluff 9–18°C, Lyttelton 7.3–19.5°C, Timaru 9.0–17.5°C, Wellington-Greta Point 10–17°C (Coakley 1970, Greig *et al.* 1988)). However, the extreme high temperatures reported of some areas of Osaka Bay during summer month are unlikely to be found in the New Zealand ports. Considering the wide distribution of *R. gibbosulum* and *G. amphioetus* in their native range from the East China Sea to Northern Japan (Hokkaido) (Nation 1975), it seems unlikely that they rely on these extreme temperatures for successful populating an area.

Explanations for the current apparent absence of the exotic cancrid species in New Zealand could either be due to a) small 'starter' populations that were too small to establish a reproductively active population, b) environmental conditions that are not compatible in the long term for these species (e.g., combination of temperature, salinity, habitat), c) changes in propagule pressure (i.e. decrease), or d) a very small population still in the lag phase of its establishment and having a low probability to be sampled. These factors and changing processes are known to influence the outcome of invasions (e.g. Carlton 1996, Ruiz *et al.* 2000).

In the first year we initially considered that the occurrence of the exotic crabs might be seasonal and similar to what has been observed in their native range. For example, in central Japan (Ise Bay) *R. gibbosulum* is one of the 10 dominant mega-benthic species but their abundance and biomass is very seasonal with highest numbers occurring during summer (Narita & Sekiguchi 2002, Narita *et al.* 2003). However, the two exotic crab species were not detected in any of the seasons at our sampling sites. Alternatively, we considered that the exotic crabs might establish themselves predominantly in deeper water (more than 12 m) in New Zealand, although known from shallow (1 m) to deep (over 100 m) water in its native range. When we did sample down to 10–20 m by dredging Lyttelton and Wellington Harbour we still did not detect any. *Romaleon gibbosulum* is known from its native range to quickly re-establish itself with high population densities after unfavourable oxygen depletion events after summer in shallow bays (Narita & Sekiguchi 2002, Narita *et al.* 2003). This shows that this species can be very successful in its spatial dispersal and reproductive output within a short time. However, this apparently has not happened at our sampling sites, perhaps because there is no local larval supply. Overall, the New Zealand environment appears to have similar habitats to the ones reported from their native range in Japan, and therefore could provide suitable habitat for these crab species in the future (see Part 2).

In our samples, the size frequency distribution of *M. novaezelandiae* varied with location, but overall mostly larger crabs (> 50 mm carapace width) were collected. The size at onset of maturity (SOM, 50% of individuals are mature) and minimum size of maturity for crustaceans and other marine organisms can vary with the geographic region. It appears that there is also a large variation for size of maturity for *M. novaezelandiae* in New Zealand. For example, in Otago Harbour the SOM for *M. novaezelandiae* is larger than >65 mm CW for males and >70 mm CW for females. There, the smallest ovigerous female was 61.5 mm (CW) out of 67 (Chatterton 1990). In our samples, the smallest ovigerous female was 51.9 mm (CW) and the smallest ovigerous female found so far in New Zealand was 24.1 mm (CW) from Banks Peninsula (Te Papa collection, AB pers. obs.).

Part 2. Size distribution, habitat and parasite investigations of the crabs *Glebocarcinus amphioetus* and *Romaleon gibbosulum* (Crustacea: Cancridae) in their native distribution

2.1 ABSTRACT

The parasite fauna of the cancrid crabs, *Glebocarcinus amphioetus* and *Romaleon gibbosulum*, was investigated in their native habitat in Japan to assess the risk of diseases to be potentially introduced to non-native areas along with the hosts to New Zealand. Investigations were carried out in July and August 2006 using fresh and preserved material from over 20 locations around Japan, but primarily from Ise Bay and Osaka Bay (Honshu). All crabs were examined externally and some also internally for the presence of parasites and symbionts. A total of 160 specimens were examined: 149 *R. gibbosulum* ranging in size from 4.5–36.4 mm carapace width and 11 *G. amphioetus* ranging in size from 5.1 to 26.1 mm carapace width. No parasites or ecto-symbionts were observed externally or internally on the crabs. The smallest ovigerous female *R. gibbosulum* had a carapace width of 22.2 mm and the smallest mature male was 20.8 mm wide, which is smaller then the largest specimen found in New Zealand. Consequently, the original non-indigenous records from New Zealand probably contained mature adults that could have potentially bred. It appears from the information gathered on depth distribution and habitat utilisation in Japan that these two Asian cancrid species occupy in part a very similar habitat to that of the New Zealand endemic cancrid crab *Metacarcinus novaezelandiae*, and the common grapsid crabs *Hemigrapsus crenulatus* and *H. sexdentatus*, which occur in the rocky to sandy, shelly intertidal and subtidal sheltered parts of the New Zealand coastline. These coastlines are common throughout New Zealand and the exotic crab species could potentially have a widespread distribution. However, more detailed information from their native habitat and on their biology is required to make more precise prediction of the target species here in New Zealand. The absence of parasites and symbionts in our samples is not unusual for cancrid crabs as only eight out of 31 cancrid crab species are currently reported to carry parasites, symbionts or other diseases.

2.2 INTRODUCTION

It has been suggested that marine invasive species are in part successful invaders because they lack their natural enemies, such as parasites and diseases in their invaded area (Torchin *et al.* 2003). For example, the globally introduced European shore crab *Carcinus maenas* is thought to be a successful invader in part because it encounters fewer parasites in the introduced range (Torchin *et al.* 2001). *C. maenas* has a reported parasite species richness of ten in its native range, which includes Fecampida, Trematoda, Cestoda, Nemertea, Acanthocephala, Nematoda, Copepoda, Rhizocephala and Isopoda. In comparison, initially only seven parasite species infected *Carcinus maenas* in its introduced range and these include Trematoda, Nemertea, Acanthocephala, Nematoda and Copepoda. The combined average prevalence of these parasites was 32% in the native range but only 9% in the introduced range (Torchin *et al.* 2002). It has been suggested, that the two Australian native tapeworms (tryponorhynch cestodes) infecting *C. maenas* in Australia are in part responsible for lower crab densities as

sites with highest infestation had lowest crab densities (Gurney *et al.* 2004). Another example is the Japanese shore crab *Hemigrapsus sanguineus* which has two reported parasite species (Trematoda, Rhizocephala) from its native range and only one (Nematoda) from its introduced range (Torchin *et al.* 2002). It has been shown, that the longer invaders are established and the wider the area in their introduce range the more new parasites they encounter and acquire. However, the number of novel parasites is typically only a fraction of the number lost (Torchin & Mitchell 2004).

In a few cases, the parasites of exotic crabs have also been introduced and these may impact native crab species if parasites can infest novel hosts. For example, the parasitic barnacle *Loxothylacus panopaei* was introduced to Chesapeake Bay most probably with infected crabs hiding among oysters transplanted for aquaculture purposes from the Gulf of Mexico (Van Engel *et al.* 1965). In its introduced range *L. panopaei* infects now three crab species of which two are novel (Hines *et al.* 1997). In the last decade, the parasitic barnacle *Heterosaccus dollfusi* has become established in the Mediterranean Sea, where its natural host the swimming crab *Charybdis longicollis* arrived through the Suez Canal about 40 years earlier (Galil & Lützen 1995, 1996, Galil & Innocenti 1999). However, no records currently report other novel hosts in the introduced range of the parasitic barnacle. In these cases, the parasites where presumably introduced via aquaculture (*L. panopaei*) and migration (*H. dollfusi*) with their hosts.

We wanted to investigate whether the Asian crabs *Romaleon gibbosulum* and *Glebocarcinus amphioetus* (Decapoda: Cancridae) have parasites or diseases in their native range of Japan which they might 'leave behind' or potentially introduce to New Zealand. This information could then be used in the future to compare the parasite fauna of these Asian crabs from their native range with their introduced location of New Zealand.

Very limited information was available on basic biology and life history aspects of the two Asian crab species *R. gibbosulum* and *G. amphioetus* (Decapoda: Cancridae) that were recorded in New Zealand waters in 2001 and 2003, respectively (Inglis 2005, 2006a, b, c, d). More information was needed to assess their habitat requirements and their potential impact of the new arrivals in New Zealand.

The aim of this project was therefore to a) investigate the size distribution of these species, b) to collect information on their habitat requirements, and c) to investigate their parasite and symbiont fauna in their native range in Japan.

2.3 METHODS

The parasite fauna of the non-indigenous cancrid crabs, *G. amphioetus* and *R. gibbosulum*, was investigated from their native habitat in Japan in July and August 2006 using fresh and preserved material. Crabs examined included live and frozen specimens collected in Ise Bay and Misake and preserved material from the Seto Marine Laboratory Collection and Osaka Museum of Natural History (Table 2.1; Appendix 2. Registration numbers of material examined of the Osaka Museum of Natural History; no reference numbers are available for the Seto Marine Laboratory Collection specimens).

Crabs from Ise Bay were collected using a dredge from a boat for a benthos project from Mie University in May and June 2006 and then preserved. For this, a sled (165 cm width x 30 cm

height entrance followed by a 440 cm long net of 2.7 cm mesh size) was towed several times 900 m along the bottom at a ship speed of 2 knots at depths of 10 m to 30 m.

Crabs from Misake were collected in July 2006 by AB and two field assistants using SCUBA in coastal shallow water of up to 10 meters depths. A hand net (25 cm diameter metal ring holding 30 cm long cone shaped netting (1 mm mesh size) was used to dig up sediment (sandy, shelly, muddy) which was then carefully sifted on shore. Approximately 100 benthos samples were taken in an area of 100 m x 30 m. In August 2006 crabs were collected from the northern part of Osaka Bay using a trawl net at about 20 m depths by scientists of the Osaka Prefectural Fisheries Experimental Station.

All crabs were examined externally and the 41 individuals from Ise Bay also internally for the presence of parasites. Museums material and the Seto Marine Laboratory collection material was only allowed to be investigated externally. The gender of all crabs was recorded and measurements were taken of the carapace width using digital callipers to the nearest 0.1 mm. The reproductive stage of the females was determined by assessing whether females were either ovigerous or not, the presence of sperm plugs in the gonopore, and the development of the gonads. Males were identified as mature when the vas deferens were fully developed and contained spermatophores. The exoskeleton, branchial chamber, gills, and internal organs (in particular the hepatopancreas, foregut, gonads, and muscle tissue) of the host were examined under a binocular microscope at 160 x for parasites and ecto-symbionts.

Table 2.1. The cancrid crabs *Romaleon gibbosulum* and *Glebocarcinus amphioetus* examined from various locations of their native range in Japan.
*Material examined from the Seto Marine Laboratory Collection. ** Material examined from the Osaka Museum of Natural History collection (Registration Numbers see Appendix 2).

Romaleon gibbosulum			*Glebocarcinus amphioetus*		
n (males - females)	collection dates	collection locations	n (males - females)	collection date	collection location
41 (27-14)	May, June 2006	Ise Bay, Honshu	0	May, June 2006	Ise Bay, Honshu
11 (5-6)	July, August 2006	Misake and Osaka Bay, Honshu	5 (2-3)	July 2006	Misake and Osaka Bay, Honshu
8 (5-3)	1956; some unknown	*Wakaura; Sisozima; Siraoi, Hokkaido; some unknown	1 (0-1)	1960	*Sirikisinai
89 (39-50)	1970-2003	**: Hyogo Prefecture (Hiraiso, Mitsu, Shio, Ootani); Kagawa Prefecture (Marugame); Mie Prefecture (Estuary of Kushida River, Toba); Osaka Prefecture (Awajishima Is., Kishiwada, Sakai); Yamaguchi Prefecture (Aio);	5 (3-2)	1969-1983	**: Hyogo Prefecture (Kobe); Mie Prefecture (Kamishima); Osaka Prefecture (Tannowa, Tarui)

2.4 RESULTS

2.4.1 Size distribution of *Romaleon gibbosulum* and *Glebocarcinus amphioetus*

A total of 160 specimens were examined from their native habitat in Japan: *Romaleon gibbosulum* (n = 149; carapace width 4.5 to 36.4 mm) and *Glebocarcinus amphioetus* (n = 11; carapace width 5.1 to 26.1 mm) (Figure 2.1). The carapace width of the smallest ovigerous female *Romaleon gibbosulum* was 22.2 mm and of the smallest mature male 20.8 mm. No ovigerous female *G. amphioetus* were found, but a female of 26.1 mm carapace width had sperm plugs in the gonopores indicating that it mated previously and is mature.
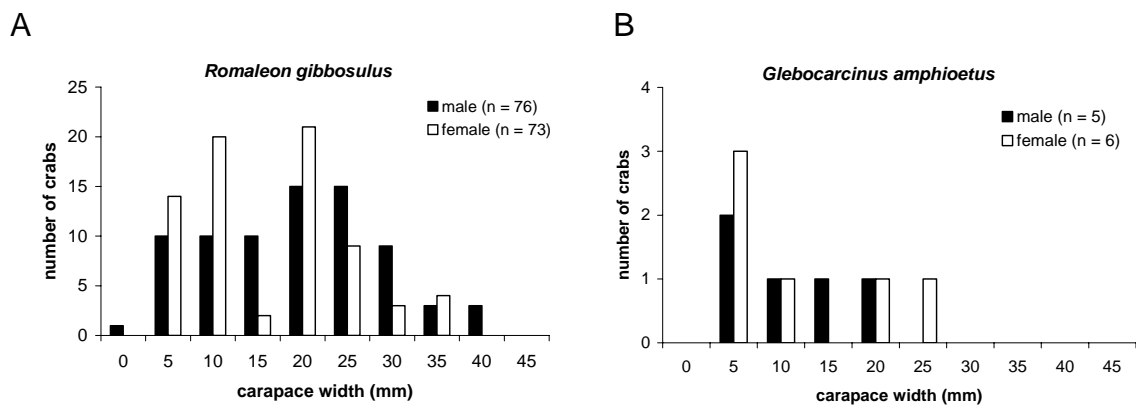
Figure 2.1 Size distributions of *Romaleon gibbosulum* and *Glebocarcinus amphioetus* examined and combined from collections made in Ise Bay, Osaka Bay and collection material from the Seto Marine Laboratory and Osaka Museum.

2.4.2 Habitat observation in the field and from the literature

Romaleon gibbosulum

Our main field site was Ise Bay where the habitat consisted of muddy to shelly bottoms which are annually exposed to very low oxygen conditions (Narita & Sekiguchi 2002, Narita *et al.* 2003). In other locations in Japan, the habitat of *R. gibbosulum* consists of muddy-sandy or broken shelly and sandy bottoms (Sakai 1976, Ai-Yun & Si-Liang 1991). Crabs have also been found among live tube-forming annelids (*Lygdamis*) and also their empty tubes in sandy to gravely bottoms (Miyadi 1940). The depth distribution of R. gibbosulum ranged from 3.7 m to 50 m in our samples. They have also been reported from 30 m depth (Ito & Honma 2001), 30–100 m (Sakai 1976) and 33–238 m (Yokoya 1933). It appears to be relatively tolerant to a range of salinities as it occurs in regular oceanic conditions as well as in estuaries with changing salinities (Table 2.1). Ovigerous female R. gibbosulum, examined in this study, were found at depths between 8.9 and 50 m.

R. gibbosulum native distribution includes Japan, coast of Korea to Northern China (Liaodong Pen) (Sakai 1976, Ai-Yun & Si-Liang 1991). In Japan, R. gibbosulum occurs around the entire coast around Honshu, Shikoku and Kyushu (Sakai 1976), as well as around northern and southern Hokkaido (Komai et al. 1992, Honma & Muraoka 1992).

Glebocarcinus amphioetus

We collected juvenile crabs at a sandy, shallow subtidal site near Misake (Honshu). In other locations in Japan, the habitat of *G. amphioetus* includes weedy beaches near the low tide mark (Ai-Yun & Si-Liang 1991) and rocky beaches from intertidal to 65 m deep (Sakai 1976). *G. amphioetus* is also reported from deeper water of 25–125 m depth in trawls taken from the continental shelf in the Gulf of California (Hendrickx 1996 as cited in Inglis et al. 2006a) and of 200 to 260 m depth in Taiwan (Wei-Rung et al. 1999 as cited in Inglis et al. 2006a). Ovigerous females have been found in the intertidal in Hokkaido (Iwata & Konishi 1981).
Glebocarcinus amphioetus native distribution is wide ranged and includes locations in the North-West and North-East Pacific. It can be found in the East China Sea, Yellow Sea and Sea of Japan (i.e. Japan, Korea, and China) (Nation 1976, Galysheva 2004). According to the

literature it is 'common' in Japan where it is recorded from the entire coasts around Hokkaido, Honshu, and Kyushu (Nations 1976; Takeda & Hyashi 1990; Komai et al. 1992). In addition, it can be found from La Jolla, California to the Gulf of California, Mexico, but does not appear to be common in some locations such as Southern California (Sandoval & Bravo 1992, Williams et al. 1989).

2.4.1 Parasite fauna and ecto-symbionts
 No parasites or symbionts were observed in the crabs *Romaleon gibbosulum* and *Glebocarcinus amphioetus* examined from over 20 locations in Japan.

2.5 DISCUSSION

2.5.1 Size distribution of *Romaleon gibbosulum* and *Glebocarcinus amphioetus*
Romaleon gibbosulum: In Japan the smallest ovigerous female *R. gibbosulum* had a carapace width of 22.2 mm and the smallest mature male was 20.8 mm wide. In comparison, the size range of *R. gibbosulum* in New Zealand was 10.7–14.4 mm for females (n = 2) and 7–23.5 mm for males (n = 3)(pers. obs.). This indicates that at least some of the males were of mature size. Although only a limited number of *R. gibbosulum* were found in the port baseline surveys in New Zealand (Inglis *et al.* 2006 b, c, d) it is likely that some other females were also of similar size to males. Consequently, the original non-indigenous records from New Zealand indicate that mature adults were present in New Zealand waters and that some could have potentially bred.

Glebocarcinus amphioetus: Crabs examined in Japan ranged in size from 5.1–26.1 mm carapace width. This is similar to the four specimens found in New Zealand (Inglis *et al.* 2005, 2006a), where females ranged in size between 12.0–14.9 mm carapace width and the male was 21.8 mm (pers. obs.). However, as only one mature female (26.1 cm wide) could be identified of the Japanese samples, the minimum size of maturity could not be established with certainty. However, the size range reported of *G. amphioetus* in New Zealand is probably near maturity because the largest New Zealand specimen was 21.8 mm wide and the known mature crab from Japan was 26.1 mm wide.

2.5.2 Habitat of *Romaleon gibbosulum* and *Glebocarcinus amphioetus*
It appears from the information gathered on depth distribution and habitat utilisation in Japan that these two Asian cancrid species occupy in part a very similar habitat to the New Zealand endemic cancrid crab, *Metacarcinus novaezelandiae* as well as the common grapsid crabs, *Hemigrapsus crenulatus* and *Hemigrapsus sexdentatus* in the rocky to sandy, shelly intertidal and subtidal in New Zealand (McLay 1988).

Notably, *R. gibbosulum* is one of the dominant mega-benthos species in Ise Bay, Central Japan and was ranked ninth in biomass and tenth in abundance of the mega benthos (Narita *et al.* 2003). *Romaleon gibbosulum* abundance and biomass showed strong seasonal and inter-annual variations with population densities typically decreasing from summer to autumn and increasing from winter to spring or summer which appear to be linked to the oxygen content in the water (Narita *et al.* 2003).
Also *G. amphioetus* has been reported to be locally abundant. For example, an average of 0.21 crabs per square metre were found during a study on distribution patterns of benthic invertebrates in algal communities in a rocky sub-littoral area of down to 7 m depth of Northern Japan (Omori *et al.* 2000).

In Osaka Bay, where *R. gibbosulum* and *G. amphioetus* occur, surface temperatures range from 6 – 19°C and bottom temperatures from 6 – 18°C. Coastal water can warm up to 32°C in some locations (Miyadi 1940). The salinity ranges from 24–33 o/oo S depending on location (i.e. lower near the rivers) and depth (i.e. lower at surface) within Osaka Bay (Miyadi 1940). This indicates that both cancrid species are adapted to a wide range of temperatures and salinities. The recorded ranges for surface and bottom temperatures of Osaka Bay are within the range of the mean monthly temperatures recorded for New Zealand harbours (e.g. Bluff 9–18°C, Lyttelton 7.3–19.5°C, Timaru 9.0–17.5°C, Wellington-Greta Point 10–17°C (Coakley 1970, Greig *et al.* 1988)).

Considering the reported high densities in some locations of these two Asian crab species, similar densities outside its native range would have some effect on local fauna and flora through competition for food and habitat if they were to successfully establish in New Zealand.

2.5.3 Parasite fauna and crab biology

No parasites or symbionts were detected in the crabs examined during this study. This might be in part because a limited number of crabs were examined internally and the rest externally (museum material). Nevertheless, the size range of crabs covered and the diversity of locations provided a breadth of material suggesting that *R. gibbosulum* and *G. amphioetus* are not commonly infested by parasites or symbionts from the areas investigated.

In contrast, other cancrid crabs have been observed to host ectobionts, egg predators, parasites or diseases. Of the known 31 recent cancrid species eight have been reported to become infested (Table 2.1). Overall, Cancridae appear to be hosts primarily for ectobionts and to a lesser degree carry parasites and other diseases.

Table 2.2. Parasites and epibionts of cancrid crabs (Cancridae).

Cancrid crab host	Parasites and Epibionts	Location on host	Reference
Cancer bellianus	*Poecilasma crassa* (Crustacea)	external	Pinho *et al.* 2001
	P. aurantia	external	Pinho *et al.* 2001
Cancer irroratus	Protozoa and bacteria on the gills	gills	Bodammer & Sawyer 1981
	Ephelota sp. (suctorian ciliate)	gills	Sawyer *et al.* 1976
	resembling *Acineta* sp.(suctorian ciliate)	gills	Bodammer & Sawyer 1981
	peritrich ciliate (*Myoschiston*)	gills	Bodammer & Sawyer 1981
	shell disease	external	Sawyer 1991
Cancer pagurus	*Hematodinium*-like dinoflagellate yeast-like organism	internal	Stentiford *et al.* 2002
	Mesanophrys carcini (ciliate)	internal	Bang *et al.* 1972; Grolière & Leglise 1977
	Ameson atlanticum (Microsporidia)	internal	Vivares & Azevedo 1988
	Fecampia erythrocephala (Fecampiida)	internal	Kuris *et al.* 2002
	Sacculina triangularis (Crustacea)	internal	Høeg & Lützen 1985
Cancer plebejus	*Proleptus* sp. (Spirurida)	external	Riffo *et al.* 1994
	Anisakis sp. (Askaridida)	internal	Riffo *et al.* 1994
Cancer productus	*Mesanophrys pugettensis* (ciliate)	internal	Morado & Small 1994; Morado *et al.* 1999
	Balanus crenatus (Crustacea)	external	McGaw 2006
	B. glandula	external	McGaw 2006
	B. nubilis	external	McGaw 2006
	Serpulid worms (Polychaeta)	external	McGaw 2006
	Spirorbid worms (Polychaeta)	external	McGaw 2006
	Dipolydora socialis (Polychaeta)	external	McGaw 2006
	Obela spp. (Hydrozoa)	external	McGaw 2006
	Sertularella turgida (Hydrozoa)	external	McGaw 2006
	Haliclona permollis (Porifera)	external	McGaw 2006
	Mytilus californiensis (Bivalvia)	external	McGaw 2006
	Notoacmea scutum (Mollusca)	external	McGaw 2006
	Membranipora membranacea (Bryozoa)	external	McGaw 2006
	Flustrellidra corniculata (Bryozoa)	external	McGaw 2006
	Cnemidocarpa finmarkiensis (Urochordata)	external	McGaw 2006
	Ascidia callosa (Urochordata)	external	McGaw 2006
	Metandrocarpa taylori (Urochordata)	external	McGaw 2006
Metacarcinus anthonyi	*Rhizophydium littoreum* (Fungi)	on eggs	Shields 1990
	Leucothrix sp. (Bacteria)	on eggs	Shields & Kuris 1988
	Lagenidium callinectes (Fungi)	on eggs	Shields & Kuris 1988
	Carcinonemertes epialti (Nemertea)	egg predator	Shields & Kuris 1988;

Continued Table 2.2. Parasites and epibionts of cancrid crabs (Cancridae).

Metacarcinus gracillis	*Balanus crenatus* (Crustacea)	external	McGaw 2006
	B. glandula	external	McGaw 2006
	Dipolydora socialis (Polychaeta)	external	McGaw 2006
	Sertularella turgida (Hydrozoa)	external	McGaw 2006
Metacarcinus novaezelandiae	acorn barnacles, amphipods, bryozoans, ciliates, mussels, oysters, serpulid and sprirobid polychaetes	external, gills	this study, Part 3
Metacarcinus magister	*Mesanophrys pugettensis* (ciliate)	internal	Morado & Small 1994
	Nadelspora canceri (Microspora)	internal	Olson *et al.* 1994; Childers *et al.* 1996
	Chlamydia-like organism	internal	Sparks *et al.* 1985
	Carcinonemertes errans (Nemertea)	external	Wickham 1978; Wickham *et al.* 1984
	Balanus crenatus (Crustacea)	external	McGaw 2006
	B. glandula	external	McGaw 2006
	B. nubilis	external	McGaw 2006
	Serpulid worms (Polychaeta)	external	McGaw 2006
	Dipolydora socialis (Polychaeta)	external	McGaw 2006
	Sertularella turgida (Hydrozoa)	external	McGaw 2006
	Haliclona permollis (Porifera)	external	McGaw 2006
	Mytilus californiensis (Bivalvia)	external	McGaw 2006
	Alia gausatata (eggs) (Mollusca)	external	McGaw 2006
	Membranipora membranacea (Bryozoa)	external	McGaw 2006
	Schistoporella unicornis	external	McGaw 2006
	Flustrellidra corniculata (Bryozoa)	external	McGaw 2006
	Cnemidocarpa finmarkiensis (Urochordata)	external	McGaw 2006
	Ascidia callosa (Urochordata)	external	McGaw 2006
	Metandrocarpa taylori (Urochordata)	external	McGaw 2006
Romaleon antennarius	*Balanus tintinnabulum* (barnacle)	external	Carroll 1982
	Balanus crenatus	external	Carroll 1982
	Balanus aquila	external	Carroll 1982
	Tetralita squamosa (barnacle)	external	Carroll 1982
	Phragmatopoma californica (tubicolous polychaetes)	external	Carroll 1982
	Spirobranchus spinosus (tubicolous polychaetes)	external	Carroll 1982

Surprisingly, even though *R. gibbosulum* and *G. amphioetus* are locally common in their native range, little is known about their reproductive biology such as size of maturity, breeding season or reproductive behaviour. In our study, ovigerous female *R. gibbosulum* and *G. amphioetus* were found from the intertidal to 50 m depth. This is different to the New Zealand native cancrid crab *Metacarcinus novaezelandiae*, were females appear to migrate primarily to deeper water during the breeding season and are rarely caught in shallow coastal areas or harbours (McLay 1988, Chatterton 1990).

R. gibbosulum feeds on a range of prey in Ise Bay which typically includes crustaceans and polychaetes and occasionally ophiuroids, bivalves and gastropods. A large proportion of food items were unidentifiable (Narita & Sekiguchi 2002).

The invasion potential of the two Asian cancrid crabs *R. gibbosulum* and *G. amphioetus* in New Zealand is difficult to predict as limited information is currently available on their basic biology and particular their reproduction. However, they hold traits similar to other successful marine invader such as being common and widely distributed in their native range (Nation 1975, Narita *et al*. 2003), feeding on a large variety of prey (Narita & Sekiguchi 2002), tolerating varying salinities (e.g. *R. gibbosulum* distribution in Osaka Bay) and temperatures (from warmer waters in East China Sea, and southern parts of Japan (e.g. Okinawa) to colder temperature of the Sea of Japan and northern parts of Japan (e.g. Hokkaido; sea range distribution in Nation 1975). In addition, they seem not constraint by parasites as we did not find any during our investigations and we are not aware of any reported from the literature.

Part 3. Parasite fauna of the endemic crab *Metacarcinus novaezelandiae* (Crustacea: Cancridae) in New Zealand

3.1 ABSTRACT

When environmental conditions are adequate for an invader, the biotic resistance it encounters from predators, competitors or parasites and pathogens, will determine its local success. Two non-indigenous Asian cancrid crab species, *Romaleon gibbosulum* and *Glebocarcinus amphioetus*, were reported in New Zealand waters in 2001 and 2003. To assess the biotic resistance they would encounter we investigated the parasite fauna of the closely related endemic cancrid crab *Metacarcinus novaezelandiae* to evaluate whether native parasites occur that could increase the biological resistance and potentially act as biological control agents in New Zealand. *M. novaezelandiae* were collected and examined from Feb. 2005 to March 2007 from the North and South Island.

A castrating barnacle, *Heterosaccus* sp. (Cirripedia: Rhizocephala) was rediscovered in New Zealand after original recordings from collections in 1931. *Heterosaccus* sp. occurred in 93.5% of 1118 *Metacarcinus novaezelandiae* (Decapoda: Cancridae) collected from Wellington Harbour between May 2006 and March 2007. Surprisingly, this rhizocephalan has so far not been found anywhere else in New Zealand even though 2591 were collected from other sites. Of the parasitized crabs, 22.1% had a rhizocephalan externa, 62.7% had a scar and 15.2% had only the interna. Prevalence of *Heterosaccus* sp. was similar for male and female crabs and all were castrated. Many of the infected males displayed major morphological changes which included a wider abdomen and extra pairs of biramous pleopods on the abdomen compared to uninfected males (feminisation). Newly emergent externa and externa filled with eggs or embryos were found throughout the year indicating a year around reproductive cycle. However, virgin externa were more common at the beginning of the southern hemisphere summer.

A literature survey of Rhizocephala in the South Pacific revealed overall few described species (18 from six genera). Several other specimens have been reported from new hosts, including some from deep sea locations, and other rhizocephalan genera but await description and identification yet. This shows clearly that the South Pacific has a rich rhizocephalan fauna, but little is known about their ecology.

The discovery of a new rhizocephalan parasite is important for our understanding of the population dynamics of native and exotic New Zealand crabs. The parasitic barnacle has a highly localised distribution and it appears that the Wellington Harbour population of the host crab is sustained by recruitment from outside the harbour as the high castration rate in the harbour is unlikely to allow for sufficient larval supply to maintain the population. However it remains unclear why Wellington Harbour is the only locations that harboured the parasite even though the crab host is widespread in New Zealand.

This new found species might play an important role in the biotic resistance of New Zealand's marine environment by lowering densities of exotic crabs. Comparative genetic work has been carried out on the New Zealand *Heterosaccus* species and it was shown that the New Zealand species is most closely related to the European species *Sacculina carcini*, which infects among others the European shore crab *Carcinus maenas*. The New Zealand

Heterosaccus might provide the first line of defence should *Carcinus maenas* make it across the Tasman Sea from Tasmania, where it has established self sustaining populations.

3.2 INTRODUCTION

One hypothesis of why invasive species are so successful is that they typically leave their natural enemies behind. In its native range, a species is kept in 'check' by predators, parasites and diseases: when introduced to an environment without these natural enemies, the species can survive and reproduce more successfully (the 'enemy release hypothesis'; Keane & Crawley 2002, Torchin *et al.* 2003, Colautti *et al.* 2004).

Counteracting this is the 'biotic resistance' a species will meet when introduced to a new location: exotic species may be poorly adapted for coping with native predators, parasites and diseases (Parker & Hay 2005, DeRivera *et al.* 2005). In theory, this means that the more diverse a new habitat is, the more likely one of the native species will prey on, compete with or infect the exotic species. For example, predation by the North American native blue crab (*Callinectes sapidus*) appears to limit the southern distribution of the invasive European shore crab (DeRivera *et al.* 2005).

Against the backdrop of 'enemy release' and 'biotic resistance' hypotheses, we investigated whether native New Zealand marine parasites exist that could potentially limit the abundance and distribution of introduced crabs.

We were interested in this research question because two non-indigenous Asian cancrid crab species, *Romaleon gibbosulum* and *Glebocarcinus* amphioetus, were reported in New Zealand waters in 2001 and 2003. The New Zealand marine fauna has few reported parasites that could attack exotic crabs and thereby defend our shores. However, elsewhere in the world, it has been shown that a large variety of parasites have a strong impact on crustacean populations (e.g. Rohde 2005).

Here, we investigated the parasite fauna of the endemic crab *Metacarcinus novaezelandiae* (Cancridae) to evaluate whether native parasites could potentially act as biological control agents against the spread of the exotic cancrid crabs. *Metacarcinus novaezelandiae* was selected as it is in the same family as the recorded non-indigenous Asian crabs *Romaleon gibbosulum* and *Glebocarcinus amphioetus* (Cancridae) in New Zealand waters. In addition, parasites or diseases are more likely to infect members of the same genus or family.

The aim of this study was therefore to a) investigate the parasite fauna of the crab *Metacarcinus novaezelandiae* from various sites in New Zealand, b) to describe the seasonal occurrence of the castrating barnacle *Heterosaccus* sp. in its crab host *Metacarcinus novaezelandiae* in Wellington Harbour, New Zealand and the morphological changes in its male host, and c) provide an overview of the diversity of Rhizocephala in the South Pacific.

3.3 METHODS

Metacarcinus novaezelandiae were collected between April 2006 and May 2007 in Wellington Harbour using baited crab traps left overnight for 12 - 24 hours at depths between 2–10 m (See also collection details in Part 1). Crabs were collected primarily from Burnham Wharf in Evans Bay (within 1 km of 41°18′748S, 174°48′708E) (n = 683) and Seaview Wharf

near Petone (within 1 km 41°15.446′S, 174°53. 948′E)(n = 421) and some were collected from wharves at the Centre Port (within 1 km 41°16.223′S, 174°47.244′E)(n = 14). Other *Metacarcinus novaezelandiae* populations were also sampled from the ports of Lyttelton, Timaru, Gisborne, Bluff and other sites on Banks Peninsula (see Part 1, Table 1.1). Most crabs were kept alive and taken to the laboratory where they held under a 12 h light-dark cycle in tanks with circulating seawater of 12–15 C and fed opened mussels until dissection. All crabs were examined externally. In addition, all crabs from Wellington, Bluff, Gisborne and a sub sample from Lyttelton Harbour (n = 268), Timaru (n = 157) and Banks Peninsula (n = 151) were examined internally. Before dissection crabs were cooled down in a freezer for 1 hour or alternatively either frozen or preserved (ethanol or formalin) for storage and later examination. The gender of all crabs was recorded and measurements were taken of the carapace width using digital callipers to the nearest 0.1 mm. The reproductive stage of the females was determined by assessing whether females were ovigerous or not. The exoskeleton, branchial chamber, gills, and internal organs (in particular the hepatopancreas, foregut, gonads, and muscle tissue) of the host were examined under a binocular microscope at 160x. The number and location of parasites were recorded.

In the course of our sampling, rhizocephalan parasites were discovered (see Results, Discussion), which necessitated the use of a specific characterisation system and extra measurements. For this the penultimate abdominal segment (5th segment) width was measured for all crabs from Wellington and a sub sample from Lyttelton Harbour for comparison. The number and location of pleopods under the male abdomen were recorded. Parasitized Crabs parasitized with a rhizocephalan were externally identified by either presence of a rhizocephalan sac on the ventral surface of the abdomen, having a circular black scar under the abdomen where a sac used to be, or presence of internal roots. All crabs without external signs of parasitism were dissected and examined internally for the presence of the internal root system using a binocular microscope. In addition, some parasitized males could be identified externally by the presence of extra pleopods on the 3rd to 5th abdominal segments or having bi-ramous 2nd gonopods. The location, size (width as the distance between the lateral margins; length as the distance between mantle opening and stalk base and depth to the nearest 0.1 mm was measured using digital callipers) and colour of the rhizocephalan sacs and scars were noted.

In addition, four developmental stages of externae were distinguished: newly emergent virgins (V) which are typically less than 5 mm long; immature (I); mature with developing embryos (ME) and advanced, eyed embryos or nauplii (MA)(as described in Gurney *et al.*. 2006). All externae were inspected externally and measured within 2 days after collection. However, many were kept alive to see whether they would produce a second externa and for these the developmental status of the brood inside the externa could not be assessed. Many crabs had sclerotised rhizocephalan rootlets and for the 622 crabs were this was investigated in more detail, the relative amount of sclerotised roots was divided into: up to 5% (I), 25% (II), 50% (III), 75% (IV) and 100% (V) of roots sclerotised.

In addition, fifty-nine *M. novaezelandiae* specimens were externally inspected at the Te Papa New Zealand National Museum, Wellington, from 19 locations collected over the past 65 years throughout New Zealand which included Akaroa (n = 7), Auckland (n = 2), Auckland Islands (n = 12), Banks Peninsula (n = 2), Bay of Plenty (n = 1), Colac Bahia Coast (n = 2), Eastbourne (n = 3), Greymouth (n = 2), Golden Gate Bridge (n = 4), Hapuka River Mouth (n = 2), Mahia Peninsula (n = 2), Marlborough Sounds (n = 1), Mataikona (n = 2), Nelson (n = 1), Otago Peninsula (n = 3), Stewart Island (n = 1), Tasman Bay (n = 1), Tory Channel (n = 1), and Wellington Harbour and surrounding open coast (n = 10).

3.4 RESULTS

In total, 3709 *M. novaezelandiae* individuals were collected and examined from Lyttelton Harbour, Banks Peninsula, Timaru, Gisborne, Bluff and Wellington and from a few other sites (Table 1.1., TePapa Collection material see methods). The only parasite found was a castrating parasitic barnacle, *Heterosaccus* sp. (Cirripedia: Rhizocephala), that was found in crabs from Wellington Harbour (Fig. 3.1).

A   B
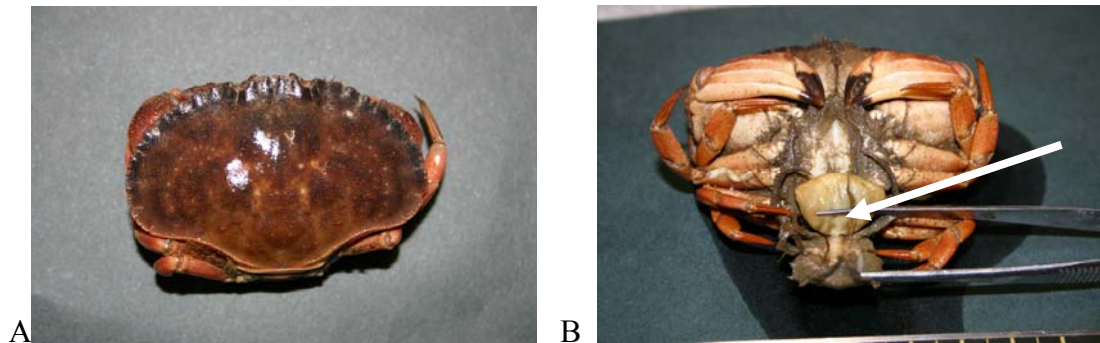
Figure 3.1. The endemic crab *Metacarcinus novaezelandiae* (A, dorsal side), infected by the parasitic barnacle *Heterosaccus* sp. (Rhizocephala) (B, ventral side of crab showing reproductive sac of parasite, see arrow). Note that only the parasite sac and its remaining scar are externally visible whereas the early infection stages with internal roots only (internas) can only be observed by dissection.

In addition, a number of ecto-symbionts were found on the carapace and gills on mostly large crabs. These included acorn barnacles, amphipods, anemones, bryozoans, ciliates, mussels, nematodes, planaria, soft and hard tube forming polychaetes, and oysters. Crabs from Lyttelton Harbour and Banks Peninsula had most commonly ecto-symbionts compared to the other locations.

A range of other crustaceans were regularly collected during our surveys (Table 1.3) and, although our focus was on cancrid crabs, we made some anecdotal observations on these. The most significant discovery was the detection of an egg predator (the ribbon worm *Carcinonemertes*) on the red rock crab *Plagusia chabrus* (Plagusiidae) in Gisborne. Almost all female crabs (13 of 14, 92.9%) were infected. The intensity ranged from 42 to 84 worms per female.

Crab host (sizes and gender) and *Heterosaccus* sp. prevalence

A total of 1118 pie crust crabs, *Metacarcinus novaezelandiae*, (565 males, 553 females) were collected in Wellington Harbour between May 2006 and March 2007. Crab size ranged from 24.1 mm to 117.5 mm (carapace width) with a relatively small median size of 51.1 mm for female and 53.5 mm for male crabs (Fig. 3.2). One-thousand-and-forty-five (93.5%) were parasitized by *Heterosaccus* sp. Of the infested crabs, 22.1% had a rhizocephalan externa, 62.7% a scar, and 15.2% the interna only. Overall *Heterosaccus* prevalence varied between 84.4% and 97.0% from May 2006 to March 2007 and no distinct seasonal patterns were observed (Fig. 3.2). However, the number of newly emergent externa peaked in early summer

(27.6% of crabs with externa in Dec.) (Fig. 3.3). Virgin externa were small (< 5 mm) and beige to light yellow and found on 18.2% of the crabs with externa.
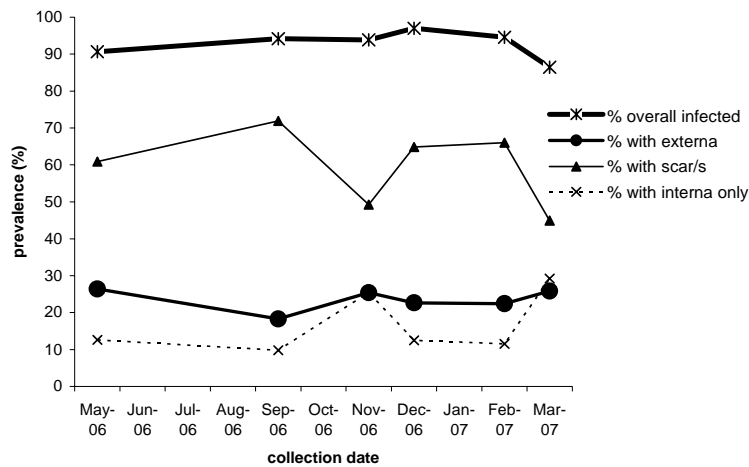

Figure 3.2. Prevalence of parasitic barnacle *Heterosaccus* sp. in the cancrid crab *Metacarcinus novaezelandiae* in Wellington Harbour.
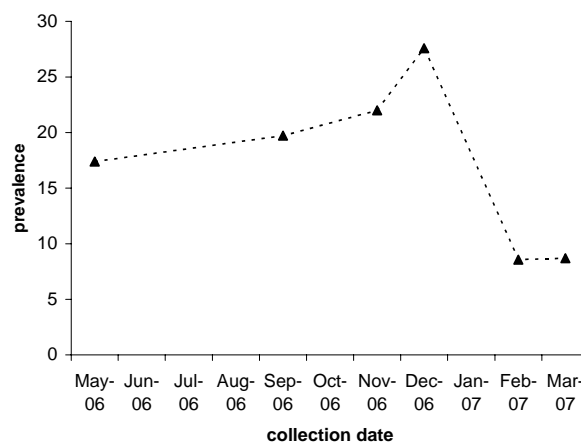
Figure 3.3. Prevalence of small, newly emerging externas of *Heterosaccus* sp. in the crab *Metacarcinus novaezelandiae* in Wellington Harbour from May 2006 to March 2007.

Overall prevalence of *Heterosaccus* sp. in male and female crabs was similar (95.4 and 91.5, respectively) as well as the prevalence within the different size groups (Fig. 3.4). The average crab size was dependent on gender and whether or not they were parasitized (ANOVA test: $F = 40.329$, $df = 3$, $P < 0.0005$). Parasitised crabs were significantly smaller than non-infected crabs. In particular, parasitised females were significantly smaller than non-parasitized females ($P < 0.0005$) and parasitised males were significantly smaller than non-parasitized males ($P < 0.0005$). In addition, parasitized and non-parasitized females were significantly smaller than their parasitized and non-parasitized male counterparts ($P = 0.013$ and $P = 0.037$, respectively). Of the two main collection sites Burnham wharf had higher infestation rates than Seaview wharf (96.4% *vs.* 92.2%).

Fifty-nine museum specimen of *M. novaezelandiae* from 19 locations throughout New Zealand were examined externally. Two of them had rhizocephalan scars and these individuals were from Wellington Harbour. None of the other locations had rhizocephalan infected crabs.
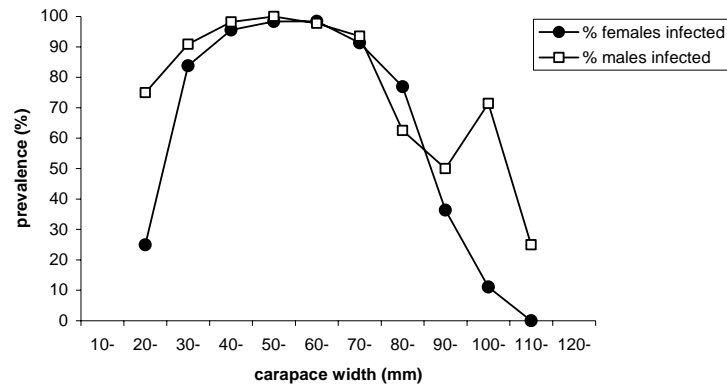

Figure 3.4. Prevalence of *Heterosaccus* sp. in different size classes of *Metacarcinus novaezelandiae* collected in Wellington Harbour from May 2006 to March 2007.

Externa and root system of *Heterosaccus* sp.

Mature externa on crabs were large (up to 24.4 mm wide and 14.5 mm long) and yellow to brown in colour. Virgin externae were small (< 5 mm) and beige to light yellow. Typically one externa or scar was found per host, but 9% of the infected crabs had two or three scars and / or sacs. The internal root system was typically clear to light orange in colour and generally found to be widespread around the gut and among the hepatopancreas. Except in a couple of cases, all crabs with externae had a healthy looking root system. In comparison, 27.7% of crabs with scars had at least some of their roots sclerotised. Mostly only a few rootlets were sclerotised (i.e., 40.7% in stage I), some crabs had up to 25% or 50% sclerotised roots (33.7% and 16.3%, respectively) and only few had the majority sclerotised (i.e., stage IV in 5.8% of crabs, stage V in 3.5% of crabs).

Effects of *Heterosaccus* sp. on male crab hosts

Infected males displayed typically major morphological feminisation. The majority had a significantly broader abdomen compared to uninfected males and similar to females (Figs. 3.5, 3.6). In addition, infected male crabs had typically clearly defined 3rd to 5th abdominal mobile segments compared to uninfected males which had their 3rd to 5th abdominal segments fused. Copulatory styles (gonopods) were often degenerate or lost. Furthermore, 43.5% of infected males (246 of 565) had extra pairs of biramous pleopods on the 3rd to 5th abdominal segments. Infected males had either one (4.4%), two (10.3%) or three (20.0%) extra pleopod pairs. Occasionally asymmetrical additions were found too, such as one single pleopod on one side only (2.8%), 1.5 (2.1%) or 2.5 (3.9%) extra pleopod pairs.
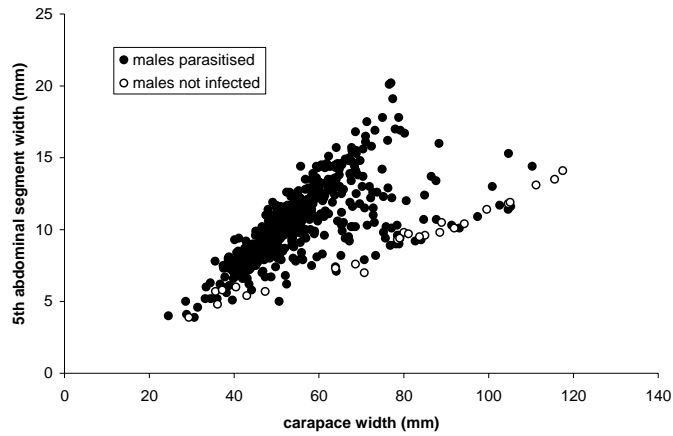
Figure 3.5. Abdominal width (5th segment) of male *Metacarcinus novaezelandiae* infected with *Heterosaccus* sp. (filled circles; n = 539) and uninfected (clear circles; n = 26) in Wellington Harbour collected May 2006 to March 2007.

Rhizocephala of the South Pacific

A total of 18 described rhizocephalan species form six genera are reported from the South Pacific (Table 3.1). This clearly shows that the South Pacific rhizocephalan fauna is diverse and uses a range of crustacean hosts. At least one species is extremely common (i.e. *Heterosaccus* sp. in Wellington), however, overall almost nothing is known about the ecology of the majority of them in the South Pacific.

Table 3.1: Described or reported parasitic barnacles (Rhizocephala) of the South Pacific. Note: ordered alphabetically by country name; ? = unidentified.

Location	Rhizocephala	Host	Reference
Australia (n = 8)	*Heterosaccus lunatus* Boschma, 1930	*Charybdis callianassa* (Brachyura: Portunidae)	Phillips (1978), Walker & Lester (1998)
	H. multilacinensis Phillips, 1978	*Charybdis truncata* (Brachyura: Portunidae)	Phillips (1978)
	Loxothylacus ihlei (Boschma, 1949)	*Scylla serrata* (Brachyura: Portunidae)	Knuckey *et al.* (1995)
	L. spinolosus (Boschma, 1928)	*Pilumnopeus serratifrons* (Brachyura: Pilumnidae)	Boschma (1957)
	Sacculina amplituba Phillips, 1978	*Ashtoret granulosa* (Brachyura: Matutidae)	Phillips (1978)
	S. duracina Boschma, 1933	*Parthenope longimanus* (Brachyura: Parthenopidae)	Phillips (1978)
	S. granifera Boschma, 1973	*Portunus pelagicus* (Brachyura: Portunidae)	Phillips (1978), Shields (1992)
	S. nectocarcini Gurney et al, 2006	*Nectocarcinus integrifons* (Brachyura: Portunidae)	Gurney *et al.* (2006)
Caroline Is. (n = 1)	*Sacculina bipunctata Kossmann, 1872*	*Portunus sp.* (Brachyura: Portunidae)	Rybakov pers. comm.
Chile/Peru (n = 3)	*Briarosaccus callosus* Boschma, 1930	Numerous lithodid crabs; cosmopolitan species	Rybakov pers. comm.
	Loxothylacus armatus Boschma, 1949	*Paraxanthus barbiger* (Brachyura: Xanthidae)	Boschma (1959)
	Peltogastrella gracilis Kroyer, 1855	*Pagurus edwardsi* (Anomura: Paguridae)	Rybakov pers. comm.
Fiji (n = 3)	*Sacculina carpiliae* Guerin-Ganivet, 1911	*Lybia tessellata* (Brachyura: Xanthidae)	Rybakov pers. comm.
	Sacculina inconstans Boschma, 1952	*Liomera bella* (Brachyura: Xanthidae)	Rybakov pers. comm.
	Sacculina leptodiae Guerin-Ganivet, 1911	*Leptodius exaratus* (Brachyura: Xanthidae)	Rybakov pers. comm.
	Thompsonia sp. (Bate, 1888)	*Betaeus malleodigitatus*	Rybakov pers. comm.
French Polynesia (n = 1)	*Temnascus foresti* Boschma, 1951	*Calcinus spiratus* (Anomura: Diogenidae)	Rybakov pers. comm.
Gilbert Is. (n = 3)	*Sacculina actaea* Guerin-Ganivet, 1911	*Actaea rufopunctata* (Brachyura: Xanthidae)	Rybakov pers. comm.
	Sacculina carpiliae Guerin-Ganivet, 1911	*Lybia tessellate* (Brachyura: Xanthidae)	Rybakov pers. comm.
	Sacculina inconstans Boschma, 1952	*Liomera bella* (Brachyura: Xanthidae)	Rybakov pers. comm.

Table 3.1 Continued:

Location	Rhizocephala	Host	Reference
New Caledonia (n = 1)	*?*	*Takedromia cristatipes* (Brachyura: Dromiidae)	McLay (1993)
New Zealand (n = 10 + ?)	*Boschmaia munidicola*	*Munida gracilis*	Lörz *et al.* (in press)
	Briosaccus callosus	*Paralomis hirtella, Paralomis birsteini*	Lörz *et al.* (in press)
	Galatheascus sp.	*Uroptychus tomentosus*	Lörz *et al.* (in press)
	Heterosaccus sp.	*Metacarcinus novaezelandiae* (Brachyura: Cancridae)	this study; Bennett (1964) – not identified
	Parthenopea n. sp.	*Vulcanocalliax* sp. nov.	Lörz *et al.* (in press)
	Peltogaster sp.	*Lophopagurus* (*Australeremus*) *kirkii*	Lörz *et al.* (in press)
	Thompsonia sp.	*Uroptychus tomentosus*	Lörz *et al.* (in press)
	Thylacoplethus sp. nov.	*Uroptychodes epigaster*	Lörz *et al.* (in press)
	Tortugaster discoidalis	*Munida subrugosa*	Lörz *et al.* (in press)
	Triangulus sp.	*Munida gracilis*	Lörz *et al.* (in press)
	?	*Trichopeltarion fantasticum* (Brachyura: Atelecyclidae)	McLay (pers. obs.)
	?	*Trichopeltarion janetae* (Brachyura: Atelecyclidae)	Ahyong (2008)
	?	*Neopilumnoplax nieli* (Brachyura: Goneplacidae)	Ahyong (2008)
	?	*Lophopagurus foresti* (Anomura: Paguridae)	McLaughlin & Gunn (1992)
	?	*Australeremus laurentae* (Anomura: Paguridae)	McLaughlin & Gunn (1992)
	?	*Australeremus cristatus* (Anomura: Paguridae)	McLaughlin & Gunn (1992)

3.5 DISCUSSION

The key finding of our survey of the parasite fauna of *M. novaezelandiae* was the discovery of the parasitic barnacle *Heterosaccus* sp. This parasite has major effects on the population dynamics of their host, for example, by inhibiting reproduction and changing male morphology and behaviour. The *Heterosaccus* sp. discovery provided the opportunity to collect data on the parasite biology and distribution, which would ultimately also provide valuable information towards our understanding of the biotic resistance exotic cancrid cabs would encounter in New Zealand waters.

Originally no records were thought to exist about parasites of the New Zealand endemic *M. novaezelandiae*, but then an old record of a parasitic barnacles (Rhizocephala) in crabs from Wellington in 1931 was rediscovered (Bennett 1964). Rhizocephalans are parasitic barnacles infecting other crustaceans. Typically, the reproductive sac (externa) of the adult female of the family Sacculinidae is sac-like and located under the abdomen of the host and the interna is a root-like system inside the crab. A crab becomes infested after a female cyprid larva settles on the host, penetrates the surface directly or after undergoing another moult to a kentrogon larva, then develops the internal root-like system and finally produces the external visible female reproductive sac. Rhizocephalan males are dwarfs that live inside the female reproductive sac (Høeg *et al.* 2005). Rhizocephala often have an effect on the morphology, physiology and behaviour of the host and can potentially have major impacts on host populations as infected hosts typically do not reproduce (Høeg *et al.* 2005).

Members of the family Cancridae are common worldwide but are, except for one, not known to harbour rhizocephalans. This is despite being the subject of many studies, such as the commercially important Dungeness crab, *Metacarcinus magister*, in the North Pacific and the European edible crab, *Cancer pagurus*, in the North Atlantic (North Sea and Mediterranean Sea). Similarly East Asian cancrid crabs from Eastern Russia (Sea of Japan), Japan and Korea have not been observed carrying rhizocephalans (A. Rybakov and A. Brockerhoff, pers. observations). Of the 31 species in the family Cancridae only *Cancer pagurus* is infected by a rhizocephalan (*Sacculina triangularis*) (Høeg & Lützen 1985).

The other epibionts encountered during this survey attached to the exoskeleton and gills (e.g. acorn barnacles, amphipods, bryozoans, ciliates, mussels, oysters, tube forming polychaetes) are of minor importance in regards to 'biotic resistance' as none of them substantially reduces reproduction and are not known to influence population dynamics of their host significantly.

Heterosaccus sp. prevalence and reproductive cycle in *M. novaezelandiae*

Large number of *M. novaezelandiae* (n = 3646) were investigated for their parasite fauna from several locations throughout New Zealand from 2005–2007 (i.e. Gisborne, Wellington, Lyttelton, Banks Peninsula, Timaru, Bluff Harbours; data not shown). However, *Heterosaccus* sp. was only found in Wellington Harbour and there parasite prevalence was extremely high. Rhizocephalan prevalence in general are typically low (less 10%), but is known to fluctuate in time and space (see examples in Hoeg *et al.* 2005). Shallow protected bays, such as Wellington Harbour, are often sites where higher infection rates occur (Werner 2001, Hoeg *et al.* 2005). Even though only a small number of museum crabs were examined of various locations from New Zealand, it is remarkable that the Wellington crabs were the only individuals infected with rhizocephalans.

Little is known about *Sacculina triangularis*, the only other reported rhizocephalan to infect cancrid crabs (*Cancer pagurus*). *Sacculina triangularis* occurs in the British Isles and possibly the Netherlands and Belgium (Høeg & Lützen 1985, Adema 1991), but not many other European locations although the host is relatively common throughout the North Sea. Similar to the New Zealand *Heterosaccus* sp. it appears to be very localised.

The New Zealand *Heterosaccus* sp. species was likely to be rare as it remained undetected for the last 75 years, until now when it had a population explosion for currently unknown reason. Known prevalence rates for *S. triangularis* in Scotland (Firth of Forth) vary from rare (0.1%–1%) to "common" in 1850s (Høeg & Lützen 1985). This indicates that *S. triangularis* may

also become occasionally very common, similar to the New Zealand species. *Sacculina triangularis* is only found on relatively small hosts (27 – 70 mm carapace width) (Høeg and Lützen 1985) whereas the New Zealand species were found in all size classes (see also below). For both species multiple infections have been observed occasionally.

As parasitized crabs are sterilised and do not reproduce it is likely that the crab population of the inner Wellington Harbour is maintained by crab larva migrating in from less infected populations such as the outer harbour region. Otherwise it would be difficult to explain how this apparently common crab can maintain its densities in the inner Wellington harbour. Similarly, the absence of a noticeable reduction of host population density in the swimming crab *Charybdis longicollis* despite relatively high prevalence of the sacculinid *Heterosaccus dollfusi* (44.4%–65.9%) in the Mediterranean was interpreted in part by the open recruitment dynamics of the crab host (Innocenti & Galil 2007).

Heterosaccus sp. was found in all size classes of its crab host. However, it seems that *Heterosaccus* sp. primarily infects juvenile and young mature crabs which grow until the externa emerges and then stop moulting and growing. This explains most likely the strong representation of relatively small crabs (40–60 mm carapace width) of which the males were usually feminised. Stunted growth is a common effect of rhizocephalans on the host crab (Høeg *et al.* 2005). Larger infected crabs had typically less morphological changes and were most likely infected at a later stage in their life. These large crabs may have immigrated into the Wellington Harbour from a less infected area outside the harbour and were then infected.

A comparison of the population size structure in Wellington Harbour with other population in New Zealand that we sampled (data not shown) showed that the mean crab size was smaller in Wellington Harbour than in Lyttelton, Gisborne and Bluff but similar to crab populations in Timaru (see Part 1), which are not infected.

Reproduction of *Heterosaccus* sp in *M. novaezelandiae* seems to occur throughout the year. However, virgin externa were more common at the beginning of the southern hemisphere summer. The reproductive cycle of the New Zealand *Heterosaccus* sp. may follow an annual pattern where many rhizocephalan sacs emerge in late spring, mature over summer with larval release in summer/autumn and finally loosing the sac in late autumn/early winter. This annual cycle of externa emergence is also supported by the fact that more than half of the infected crabs had scars. Furthermore, in a third of infected crabs, at least part of the root system is sclerotised after the externa has dropped off. It is unknown whether a new externa will be formed subsequently from the same individual. None of the about 50 crabs held in the laboratory (data not shown) for up to 6 months produced a second externa. The continuous reproductive cycle together with the enclosed harbour topography may in part explain how the parasite keeps up such a high infection rate in its host.

Anecdotal observations made in the laboratory indicate that externa growth can be fast and small externa can grow from 7 mm to 15 mm width within a month. *Metacarcinus novaezelandiae* of about 50 mm carapace width have been estimated to be about one year old for a population in Otago Harbour, South Island and there the earliest onset of maturity for females occurs at 59.4 mm CW and for males at 52.6 mm CW (Chatterton 1990). In the Golden Bay and Bay of Plenty, warmer areas of the South and North Island, much smaller ovigerous females were found (24.4 mm and 38 mm CW) (McLay 1988). Estimating from these data, it is likely that the development of the interna and externa in *Metacarcinus novaezelandiae* takes less than a year, but this should be tested in the laboratory directly, particularly the duration of the initial internal phase of *Heterosaccus* sp.

It has been shown that the duration of the internal phase can vary highly among locations for a particular species and even more between different species. For example, in *Loxothylacus panopaei* the internal phase before externa eruption takes about 3 weeks (Walker *et al.* 1992) and for *Sacculina carcini* 5–14 months (Walker 1987, Høeg *et al.* 2005). The duration from the emergence of the externa to first brood release in rhizocephalans is about one to four weeks (Høeg 1995).

Comparative genetic work has been carried out on the New Zealand *Heterosaccus* sp. and it was shown that the New Zealand species was significantly different from the other species tested and most closely related to the European species *Sacculina carcini*, which infects among others the European shore crab *Carcinus maenas* (Gurney pers. com.). The New Zealand *Heterosaccus* might provide the first line of defence should *Carcinus maenas* make it across the Tasman Sea.

Rhizocephala of the South Pacific

The South Pacific fauna of the Rhizocephala has received very little or no attention and of the approximately 250 species known worldwide (Høeg *et al.* 2005) only a few are currently described from the South Pacific. We were interested on how our observations of *Heterosaccus* sp. relate to findings of other rhizocephalans in the South Pacific and whether any trends or patterns are emerging. Essentially, the description of South Pacific rhizocephalans is in its beginnings and although 18 have been described from various countries, many have been recorded but await description yet (at least 11). Currently, no rhizocephalans have been identified and described from New Zealand waters, but one crab and three species of hermit crabs have previously been reported carrying rhizocephalans in New Zealand waters (Bennett 1964; McLaughlin & Gunn 1992). Several deep water species from seamounts have also been recorded (Ahyong 2008) or are currently being described (Glenner *et al.* in review). The South Pacific rhizocephalan fauna is diverse and at least one species is extremely common (i.e. *Heterosaccus* sp. in Wellington), however, overall almost nothing is known about their ecology.

New Zealand parasite fauna and biotic resistance

Parasites play major, though subtle, roles in host population dynamics and community structure. Parasites are an integral part of healthy ecosystems and can even been used to measure ecosystem health (Hudson *et al.* 2006). Also in coastal marine ecosystems, parasites can influence predator-prey interactions, host spatial distribution, food web stability and overall biodiversity (Torchin *et al.* 2003, Coulatti *et al.* 2004, Mouritsen & Poulin 2002, 2005). Overall, the New Zealand marine fauna has currently few reported crustacean parasites that could attack exotic crabs and thereby increase the biotic resistance encountered by invaders. The scarcity of known marine crustacean parasite is most likely caused by the lack of investigations in the past and does not reflect the true diversity of these. Some examples of marine crustacean parasites known in New Zealand include marine hairworms (Nematomorpha) (Poinar & Brockerhoff 2001), spiny headed worms (Acanthocephala)(e.g. Brockerhoff & Smales 2002), trematodes and nematodes (e.g., Poulin *et al.* 2003), and castrating isopods (Entoniscidae)(Brockerhoff 2004).

Exotic host species often evade the direct impact of parasites because they have not co-evolved with local parasites and the latter cannot infect them. According to conventional wisdom, long periods of co-evolutionary time are necessary for parasites to switch host species and expand the range of hosts they can exploit (Thompson *et al.* 2005). However, host specificity often breaks down in ecological time, with local parasites quickly adopting exotic species as new hosts, often within months or years following introduction (Lafferty *et al.* 2006, Poulin 2007).

We currently do not know what ecological characteristics of hosts or parasites allow these rapid host switches. Is the ability of a parasite to exploit new hosts primarily constrained, for example, by the phylogenetic distance or by the ecological similarity, between a novel host species and the original host? In addition, which role do parasite life history traits play in regards to the number and taxonomic diversity of host species that they can exploit?

Particularly parasites that reduce reproductive success in their hosts by castration or other means would be strong candidates for impacting on the population dynamics of exotic species. However, this would require that the native parasite species is able to infect novel hosts.

The newly rediscovered parasite *Heterosaccus* sp. in New Zealand would be a good candidate to impact on the population dynamic of the exotic crabs if it can infect them. Some Rhizocephala are very host specific whereas others are not. For example, *Sacculina carcini* has about a dozen host species from two families (Portunidae (Portunoidea) and Pirimelidae (Cancroidea)) whereas *Sacculina eriphiae* is only known from one host (Øksnebjerg 2000). Recent screening on the susceptibility of native Australian crabs for the European rhizocephalan *Sacculina carcini* showed that it could infect four novel hosts but did successfully develop to reproduce. In addition, most novel host crabs died after initial internal parasite development (Goddard *et al.* 2005). In contrast, *Loxothylacus panopaei* was able to infect successfully two novel host crabs (Hines *et al.* 1997). So far the New Zealand rhizocephalan *Heterosaccus* sp. is known from only one host (*M. novaezelandiae*), but further screening of other New Zealand crabs could reveal a higher host diversity. Whether *Heterosaccus* sp. will infect the two exotic cancrid crabs *G. amphioetus* and *R. gibbosulum* remains to be shown.

Another potentially useful candidate in regards to biotic resistance would be the newly discovered ribbon worm Carcinonemertes which is an egg predator of the New Zealand red rock crab *Plagusia chabrus* (Plagusiidae). Although our focus was on cancrid crabs, we made some anecdotal observations on a range of other crustaceans and detected this egg predator. This ribbon worm family was previously unknown from New Zealand. The ribbon worm is widespread and was found in several locations on the North and South Island from crabs collected during the surveys and from Te Papa museum specimens (pers. obs.). Its impact on crab host has not been determined yet, but other *Carcinonemertes* species are known to be able to substantially reduce the egg mass of its host (Jensen & Sadeghian 2005). There are currently twelve recognised species of *Carcinonemertes* worldwide, and these worms are all egg predators of crabs. The worm's intriguing life cycle typically includes a larval resting stage that hides under the abdomen of the crab. When a female crab lays eggs and attaches them under her abdomen, the worms come out to feed, mature, mate and reproduce on the eggs; as a result, a female crab may lose a substantial part of her brood (up to 100%).

Members of the genus *Carcinonemertes* have the potential for large scale ecological and economic impact. In North America, for example, widespread outbreaks of *Carcinonemertes errans* and *Carcinonemertes regicides* in the 1970s and 1980s led to extensive reproductive

failure in Dungeness (*Cancer magister*) and red king crabs (*Paralithodes camtschaticus*), and caused significant damage to these fisheries (Jensen & Sadeghian 2005). With respect to biotic resistance, the North American ribbon worm *Carcinonemertes epialti* has been shown to cause significant brood mortality on the exotic European shore crab, demonstrating the potential for population-level impacts on non-native crabs (Torchin *et al.* 1996). In New Zealand, it remains to be shown how host specific the newly discovered ribbon worm is among native crabs and whether is would include novel hosts such as exotic crabs in the future.

Part 4. Overview of non-indigenous brachyuran decapods worldwide

4.1 ABSTRACT

The introduction and spread of marine non-indigenous species is now recognized as one of the most significant global threats to marine biodiversity and Crustacea are playing a significant part in marine invasions. Some brachyuran species are well known for being invasive, such as the European green crab and the Chinese mitten crab, but less tends to be known about other non-indigenous brachyuran crabs. The aim of this project was to provide an overview of non-indigenous brachyuran decapod known worldwide and their distribution patterns and invasion status.

A literature review revealed that 57 species of brachyuran decapods are known as non-indigenous species, of which 32 (57.1%) have become established. Three brachyuran super-families stand out in their high number of recorded non-indigenous species: namely the Portunoidea (swimming crabs), Grapsoidea (shore crabs) and Majioidea (spider crabs), with fifteen, eight and seven species, respectively. Xanthoidea are remarkable as all of their recorded five non-indigenous species have also become established. The Cancroidea include in total six species which have been recorded outside their native range, but so far only one has become established. The families Portunidae (swimming crabs), Varunidae ('grapsid crabs') and Leucosiidae (pebble crabs) are the families with the highest number of established exotic species, ten, four and three, respectively. The Mediterranean Sea has the highest number of non-indigenous brachyuran species (42 and 19 established) as many invaded through the Suez Canal. In New Zealand four brachyuran species have been recorded (*Pyromaia tuberculata*, *Charybdis* (*Charybdis*) *japonica*, *Glebocarcinus amphioetus* and *Romaleon gibbosulum*) of which the first two have become established. In Australia three brachyuran species have been recorded and these have also become established (*Pyromaia tuberculata, Metacarcinus novaezelandiae, Carcinus maenas*).

In summary, non-indigenous brachyuran crabs are a major issue in many parts of the world (unless they are commercially fished) as they often establish high population densities and tend to compete fiercely with local fauna for food and shelter. Although the total number of non-indigenous brachyuran crabs is small compared to other major taxa (e.g., Mollusca) their impact can be substantial. Consequently, preventative measures are important as well as developing better control techniques to limit their impacts.

4.2 INTRODUCTION

The introduction and spread of marine non-indigenous species (NIS) is now recognized as one of the most significant global threats to marine biodiversity along with marine pollution, habitat alteration and overexploitation. Crustacea are playing a major part in marine bioinvasions which is occurring worldwide and at an increasing speed over the last century (Cohen & Carlton 1998; Ruiz *et al.* 2000). Of the about currently 42,000 described crustaceans many have invaded new regions, from small amphipods to large stone crabs such as *Paralithodes camtschaticus* (e.g. Dick & Platvoet, 2000 Jørgensen 2005), with several brachyuran decapods particularly successful.

The global invasive species database (Invasive species specialist group, http://www.issg.org/database) holds a list of the world's 100 worst invasive alien species and includes two brachyuran decapod species, the European green crab *Carcinus maenas* (Decapoda: Portunidae) and the Chinese mitten crab *Eriocheir sinensis* (Decapoda: Varunidae). These two crab species have been widely studied and their biology, impact and invasion history has recently been comprehensively summarised (Klassen & Locke 2007; Veilleux & de Lafontaine 2007). Most of these introductions are thought to be anthropogenic and their impacts have been diverse, from being an aggressive competitor for food and shelter, to native species, to affecting aquaculture facilities and harvests and causing structural damage to river banks (see biological synopsis of Klassen & Locke 2007; Veilleux & de Lafontaine 2007).

What about the current state of invasion and characters of the other non-indigenous marine brachyuran decapod species that have been reported worldwide? What are the emerging patterns for brachyuran invasion histories? Are there particular life history patterns in certain brachyuran families that enhance or reduce invasion potential? Could this knowledge be used to intervene early in preventing establishment or reducing the rate of dispersal of these invasive species and help in their pest management?

Biological invasions are synergistic processes which are influenced by the characteristics of the invading species and by the effects of the transport vector and the recipient environment. It is impossible to make exact and quantitative prediction of the next marine invaders, but establishing biological trends will be an important part to better understand marine invasions. For example, it is generally believed that high fecundity, planktonic dispersal, having a broad spectrum of habitat and food preferences, tolerance to a wide range of environmental conditions, longevity and a large size are usually good traits for being a successful marine invader (Hutchings *et al.* 2002). However, a particular invader typically does not comprise all of these traits and it is not always clear which of those are the most influential for successful invasion.

As a rule of thumb it has been proposed that 10% of introduced species will settle and 1% will become invasive in the terrestrial environment (Williamson & Fitter 1996), but 55% (456 of 828 species) have become established in the combined 'European Seas' (Streftaris *et al.* 2005) and 52% (385 of 745) in the Mediterranean (Zenetos *et al.* 2005).

Analysing the vectors driving marine invasions such as accidental transfer through ballast water, fouling on ship hulls, man-made canals, fisheries and aquaculture is also an essential part of assessing the invasion potential. Vector analysis is being used as a factor to rank likely next pest species too, and can be used to identify species for targeted surveys and possibly future management (Hayes *et al.* 2005).

Invasion prevention and early detection with possible eradication while invasions are still small is obviously the preferred invasion control method. However, it is also important to explore methods and techniques that might be able to mitigate the impact of the invasive species if eradication is not possible. This could include the use of native predators, competitors, parasites or diseases or very species specific collection and removing methods, such as the use of pheromones. The options for managing invasive marine species range from the more classical methods of physical removal or use of chemicals (biocides), to biocontrol, genetic technology, environmental remediation, commercial exploitation and intensification of native species (such as predators, herbivores, parasites or diseases) and others (Thresher & Kuris 2004). It appears that the acceptability of the control methods vary largely and depend on their perceived cultural and political acceptability, and likely effectiveness (Thresher &

Kuris 2004). Physical removal and biocides are seen as potential good control methods for small scale incursions, but no currently acceptable control methods are available for large-scale incursions (Thresher & Kuris 2004). It has been therefore suggested that one could develop new techniques, increase the effectiveness of acceptable techniques, or increase the acceptability of potential effective techniques (Thresher & Kuris 2004). Biological control in the marine environment has been viewed as too risky by some scientists (Secord 2003).

In 2002 and 2003 a few individuals of two exotic cancrid crab species (Decapoda: Cancridae) were found during baseline port surveys in five harbours in the North and South Island of New Zealand (Inglis *et al.* 2005, 2006 a, b, c, d). Cancrid crabs are not known for being invasive and subsequent intensive surveys for these species showed no evidence that they have become established in New Zealand as none were found subsequently (Brockerhoff pers. obs.). However, for New Zealand it is of particular importance to investigate their future potential to become established in New Zealand if they arrive here again.

Here, we provide a world overview of the 57 non-indigenous brachyuran decapod species which have been reported outside their native range, some of which became pests others not. We were particularly interested in comparing the decapod species that became successful invaders versus the ones that either failed to become establish in the first place or became established but have not developed high population densities or remained localised. What were the contributing factors in their biology that made the difference?

Using literature references and various databases we tried to examine aspects of the biology and life history of these 57 exotic brachyuran decapod species to investigate their invasion history and to assess their invasion characteristics. Fairly detailed information was found for about a third of the species, the most invasive ones, and somewhat scattered information for the rest. We concentrated on life history traits of brachyuran species or families to identify bottlenecks of population establishment or dispersal that could potentially used for pest management and included information on possible pest management options when available.

Our aim was therefore, to carry out a literature review on biological factors driving introduction and invasion potential in marine brachyuran decapods worldwide, with special attention to cancrid crabs and a New Zealand context.

4.3 METHODS

A literature survey on exotic marine brachyuran decapods in peer reviewed scientific journals was carried out using the 'Biological Abstract' database from 2001 to 2007, 'Zoological Records' database from 1985 to 2002, and 'Biosis previews' from 1991 to 2000. In addition, information was obtained from a variety of databases available on the internet, e.g. ISSG: Invasive Species Specialist Group (http://www.issg.org/database/), CIESM: Atlas of exotic crustaceans in the Mediterranean (http://www.ciesm.org/atlas/index.html), NIMPIS: National Introduced Marine Pest Information System (http://crimp.marine.csiro.au/nimpis, and others (see reference list for more details). This review deals primarily with marine species, but brackish water and catadromous species, such as *Rhithropanopeus harisii* and *Eriocheir sinensis*, where also included as they have parts of their lifecycle in the marine environment. Brachyuran classification followed the annotated checklist of extant brachyuran crabs of the world from Ng *et al.* (2008), and other recent references when available.

Following invasion definitions were used: non-indigenous or exotic species (NIS) = outside its natural geographic range; established species = species with self maintained populations or with many records; casual species = not established, species with sporadic recordings in place and time; cryptogenic species = species with no definitive evidence of their native or introduced status; invasive species = spreading, pest.

Oceanographic locations have been abbreviated as follows: At = Atlantic, Arctic = Arctic Ocean, Antarctic = Antarctic Ocean, B = Baltic, Bl = Black Sea, I = Indian Ocean, M = Mediterranean Sea, North = North Sea, P = Pacific. European 'Seas' include the Arctic, Baltic, Black Sea, Mediterranean and North Sea. The cardinal directions were abbreviated as N (North), E (East), S (South), and W (West).

4.4 RESULTS

Currently there are 93 described brachyuran families which include 6,793 described species (Ng *et al.* 2008). The literature review on exotic marine brachyuran species revealed 57 non-indigenous species in 25 families, of which 32 (57.1%) have become established in various seas and countries (Table 4.1, Fig. 4.1). Table 4.2 provides an overview on crab size, depth distribution and habitat.

Portunoidea (swimming crabs), Grapsoidea (shore crabs) and Majioidea (spider crabs) are the superfamilies with the most exotic records, fifteen, eight and seven, respectively. The families Portunidae (swimming crabs), Varunidae ('grapsid crabs') and Leucosiidae (pebble crabs) are the families with the highest number of established exotic species, ten, four and three, respectively (Fig 4.1).
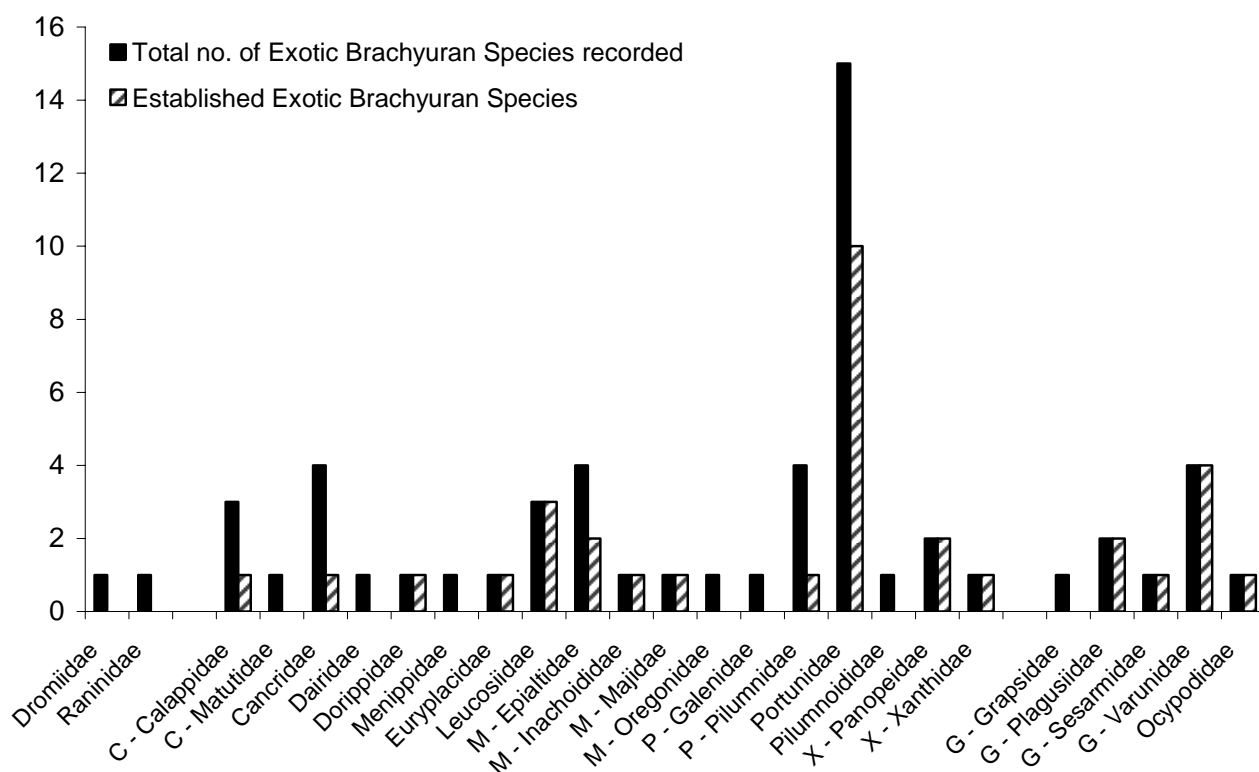
Figure 4.1. Brachyuran families in which exotic species have been recorded or have become established. Note: Taxonomic classification follows Ng *et al.* 2008 and families have been divided into three sections: Podotremata (2 families), Heterotremata (18 families), and Thoracotremata (5 families) (from left to right). Capital letter in front of family names indicate belonging into same superfamily, i.e. C = Calappoidea, M = Majoidea, P = Pilumnoidea, X = Xanthoidea, G = Grapsoidea.

Some regional observations

The Mediterranean Sea alone has 42 of the 57 exotic brachyuran species recorded worldwide of which 19 (45.2%) have become established (Table 4.1). Of these, two are described as common (*Charybdis helleri*, *Charybdis longicollis*), three as abundant to very abundant and have impact on the environment and/or economy (*Dyspanopeus sayi*, *Callinectes sapidus*, *Portunus pelagicus* (the latter however rare at some locations)), and two are regarded as invasive (*Libinia dubia*, *Rhithropanopeus harrissii*) (Zenetos *et al.* 2005). *Percnon gibbesi* which was first recorded in 2000 is showing rapid spread in the Mediterranean Sea and it has been suggested that it may be the most invasive decapod currently expanding its distribution in the Mediterranean Sea (Thessalou-Legaki *et al.* 2006). The high number of exotic brachyurans has resulted to a large degree from the migrations through the Suez Canal into the Mediterranean (Lessepsian or Erythrean migration), but also includes shipping, aquaculture and unknown introductions. In the Mediterranean, the majority (n = 37) of exotic brachyurans are exotic only there, with a few (n = 5) also exotic in other seas. Fourteen exotic brachyurans are recorded in a location other than the Mediterranean Sea, of which seven have become established (50%) (Table 4.1).

In New Zealand four brachyuran species have been recorded (*Pyromaia tuberculata, Charybdis (Charybdis) japonica, Glebocarcinus amphioetus* and *Romaleon gibbosulum*), of which, the first two have become established. In Australia three brachyuran alien species have been recorded, and have also become established (*Pyromaia tuberculata, Metacarcinus novaezelandiae, Carcinus maenas*). A regional overview in the main oceans and some seas of non-indigenous brachyuran worldwide is given in Table 4.3.

Table 4.1. Overview of native and exotic distribution and likely vectors of non-indigenous marine brachyuran decapods worldwide.
Abbreviation for oceanic regions: At - Atlantic, B - Baltic, Bl- Black Sea, I - Indian, IP - Indo Pacific; M - Mediterranean, No - North Sea; P - Pacific; N, E, S, and W are the cardinal directions. References are provided in text. Taxonomic families listed in order following Ng et al (2008) classification. Following superfamily names are abbreviated: Calappoidea (C), Majoidea (M), Pilumnoidea (P), Xanthoidea (X), Grapsoidea (G). References are provided in text.

Family	Species (underlined if established in a location)	Origin	Non-indigenous in	likely vector
Dromiidae	*Sternodromia spinirostris*	tropical & subtropical E At	M	?
Raninidae	*Notopus dorsipes*	I W P, Red Sea to Malay Archipelago	M	Suez Canal
C - Calappidae	*Calappa hepatica*	IP, Red Sea to Hawaii, Clipperton Island	M	Suez Canal
C - Calappidae	*Calappa pelii*	tropical? E At	M	?
C - Calappidae	*Cryptosoma cristatum*	tropical E At	M	?
C - Matutidae	*Ashtoret lunaris*	I W P, Red Sea to Australia	M	Suez Canal
Cancridae	*Glebocarcinus amphioetus*	NW P (E China Sea, Yellow Sea, Sea of Japan), N E P (Gulf of California)	SW P (New Zealand)	hull fouling or ballast water
Cancridae	*Metacarcinus magister*	NE P	NW At (Massachusetts), NW P (Japan)	accidental release?
Cancridae	*Metacarcinus novaezelandiae*	SW P (New Zealand)	SW P (South Australia, Tasmania)	accidental transfer with oysters
Cancridae	*Romaleon gibbosulum*	NW P (E China Sea, Yellow Sea, Sea of Japan)	SW P (New Zealand)	hull fouling or ballast water
Dairidae	*Daira perlata*	I W P	M	Suez Canal

Table 4.1. Continued**: Overview of native and exotic distribution and likely vectors of non-indigenous marine brachyuran decapods worldwide.**

Family	Species (underlined if established in a location)	Origin	Non-indigenous in	likely vector
Dorippidae	_**Dorippe quadridens**_	I W P (Red Sea to Australia and China)	M	Suez Canal
Menippidae	**Sphaerozius nitidus**	I W P	M	Suez Canal
Euryplacidae	_**Eucrate crenata**_	IP (Red Sea to Hawaii)	M	Suez Canal
Leucosiidae	_**Ixa monodi**_	Red Sea	M	Suez Canal
Leucosiidae	_**Coleusia signata**_	I W P	M	Suez Canal
Leucosiidae	_**Myra subgranulata**_	W I (Red Sea to Madagascar)	M	Suez Canal
M - Epialtidae	_**Herbstia nitida**_	tropical E At (Gulf of Guinea)	M	?
M - Epialtidae	**Hyastenus hilgendorfi**	I W P (Red Sea to Malay Archipelago)	M	Suez Canal
M - Epialtidae	_**Libinia dubia**_	W At (from Massachusetts to Cuba)	M	ballast water
M - Epialtidae	**Menaethius monoceros**	IP (Red Sea to Hawaii and Tahiti)	M	shipping
M - Inachoididae	_**Pyromaia tuberculata**_	NE P (Gulf of California to Panama Canal)	SW At (Brazil, Argentina), NW P (Japan), SW P (Australia, NZ)	ballast water
M - Majidae	_**Micippa thalia**_	I W P	M	Suez Canal
M - Oregoniidae	**Hyas araneus**	N At (from Iceland, Spitzbergen and European Russia to the English Channel)	Southern Ocean	?
P - Galenidae	**Halimede tyche**	I W P (Persian Gulf to Australia)	M	Suez Canal
P - Pilumnidae	**Actumnus globulus**	Red Sea, W I	M	shipping

Table 4.1. Continued**: Overview of native and exotic distribution and likely vectors of non-indigenous marine brachyuran decapods worldwide.**

Family	Species (underlined if established in a location)	Origin	Non-indigenous in	likely vector
P - Pilumnidae	*Glabropilumnus laevis*	I	M	Suez Canal
P - Pilumnidae	*Pilumnopeus vauquelini*	Red Sea, Persian Gulf	M	Suez Canal
P - Pilumnidae	*Pilumnus minutus*	I W P	M	Suez Canal
Portunidae	*Callinectes danae*	W At (from North Carolina to Brazil)	M	shipping
Portunidae	*Callinectes sapidus*	N & S W At (from Nova Scotia to Uruguay)	B, Bl, M, No, NE At, NW P (Japan), Hawaii	vessel fouling, ballast water, deliberate or accidental release by individuals
Portunidae	*Carcinus aestuarii*	M, Canary Islands	NW P (Japan), SE At (Cape Town)	shipping, ballast water
Portunidae	*Carcinus maenas*	E At, North Sea, Baltic	N & S At, N & SW P	dry ballast, ship hulls, ballast water, fisheries
Portunidae	*Carupa tenuipes*	IP (from Red Sea to Japan, Australia, Polynesia and Hawaii)	M	Suez Canal
Portunidae	*Charybdis feriata*	I P (E & S Africa, from China and Japan to Australia)	M	seafood holding tank on merchant ship
Portunidae	*Charybdis hellerii*	I W P (Red Sea to new Caledonia)	M, NW & SW At (Florida to Brazil)	Suez Canal
Portunidae	*Charybdis japonica*	China, Japan, Korea, Taiwan, Malaysia	SW P (New Zealand)	vessel fouling, ballast water

Table 4.1. Continued**: Overview of native and exotic distribution and likely vectors of non-indigenous marine brachyuran decapods worldwide.**

Family	**Species** (underlined if established in a location)	**Origin**	**Non-indigenous in**	**likely vector**
Portunidae	_**Charybdis longicollis**_	IP	M	Suez Canal
Portunidae	**_Liocarcinus navigator_**	E At, M, Adriatic S, Bl	SW At	?
Portunidae	_**Portunus pelagicus**_	IP	M	Suez Canal
Portunidae	_**Scylla serrata**_	IP, Red Sea to Tahiti	Hawaii, SW At (Brazil)	intentionally for fishery
Portunidae	**_Thalamita gloriensis_**	I W P	M	shipping, maritime traffic
Portunidae	**_Thalamita indistincta_**	IP	M	Suez Canal
Portunidae	_**Thalamita poissonii**_	I W P (Red Sea to Taiwan)	M	Suez Canal
Pilumnoididae	**_Pilumnoides inglei_**	?	No	?
X - Panopeidae	_**Dyspanopeus sayi**_	NW At	M	ballast transport, accidental transfer with clam seed
X - Panopeidae	_**Rhithropanopeus harrisii**_	NW At	B, Bl, M, No, NE P, NE At	ballast water, accidental transfer with clam/oyster seed, vessel fouling
X - Xanthidae	_**Atergatis roseus**_	IP (Red Sea to Fiji)	M	Suez Canal
G - Grapsidae	**_Grapsus granulosus_**	Red Sea	M	Suez Canal, vessel fouling

Table 4.1. Continued**: Overview of native and exotic distribution and likely vectors of non-indigenous marine brachyuran decapods worldwide.**

Family	Species (underlined if established in a location)	Origin	Non-indigenous in	likely vector
G - Plagusiidae	*Percnon gibbesi*	N & S E At (California to Chile), N & S W At (Florida to Brazil), Madeira to G Guinea (N & S E At)	M	shipping; via Strait of Gibraltar
G - Plagusiidae	*Plagusia squamosa*	IP (Red Sea to eastern Pacific)	M	Suez Canal, as fouling organism
G - Sesarmidae	*Nanosesarma minutum*	I W P (E Africa to Thailand)	NW P (Hawaii)	ballast water ?
G - Varunidae	*Eriocheir sinensis*	NW P (SE Asia; China, Korea)	B, Bl, M, No, NE At, NW At, Lake Erie to Mississippi Delta to California	canals, shipping?
G - Varunidae	*Hemigrapsus penicillatus**	NW P (Japan to Taiwan, Hong-Kong, Hawaii?)	No, NE At	ballast water ?
G - Varunidae	*Hemigrapsus sanguineus*	NW P (from Sakhalin to Hong Kong and Japan)	NE At (France, Netherlands), NW At (New Jersey - Massachusetts to N Carolina), M	ballast water
G - Varunidae	*Hemigrapsus takanoi**	NW P (Japan to China, Hawaii?)	NE At, No (Spain, France, Belgian, Netherlands)	vessel fouling, ballast water
Macrophthalmidae	*Macrophthalmus graeffei*	WIP	M	Suez Canal

* Identity requires clarification in some locations, i.e. whether it is *Hemigrapsus penicillatus* or *H. takanoi*

Table 4.2. Overview of size, depth distribution and habitat in native range of non-indigenous marine brachyuran decapods worldwide. Taxonomic families listed in order following Ng et al (2008) classification. Following superfamily names are abbreviated: Calappoidea (C), Majoidea (M), Pilumnoidea (P), Xanthoidea (X), Grapsoidea (G). References are provided in text.

Family	**Species** (underlined if established in a location)	**Common size or max. size**	**Depth distribution**	**Habitat**
Dromiidae	*Sternodromia spinirostris*	CL 6.4 cm (max.)	8-108 m	sand, mud bottoms
Raninidae	*Notopus dorsipes*	CL 2.5 cm	50-100 m	sandy bottoms
C - Calappidae	*Calappa hepatica*	CL 5.1 (max)	intertidal to 100 m	sandy, muddy or gravel bottoms
C - Calappidae	*Calappa pelii*	CL males 5.9, fem 5.6 cm	20-400 m, mostly between 50-150 m	muddy bottoms
C - Calappidae	*Cryptosoma cristatum*	CL males 5.9 cm	intertidal to 75 m	sandy or coralligenous bottoms
C - Matutidae	*Ashtoret lunaris*	CL males 5.5 cm, fem 5.1 cm	subtidal	sandy, muddy-sand
Cancridae	*Glebocarcinus amphioetus*	CW males 4.1 cm, fem 3.1 cm	intertidal to 65 m; also down to 260 m	weedy or rocky beaches near the low tide mark
Cancridae	*Metacarcinus magister*	CW 15.1 cm (up to 20 cm)	intertidal to 107 m	eelgrass, sandy shelly bottoms
Cancridae	*Metacarcinus novaezelandiae*	CW males 15 cm, fem 11.2 cm	intertidal to 40 m (possibly deeper)	under stones, among large seaweed in intertidal, on sandy bottom in deeper water
Cancridae	*Romaleon gibbosulum*	CW male 4.2 cm	33-238 m	muddy-sandy or broken shelly and sandy bottoms
Dairidae	*Daira perlata*	CL 3.5 cm (max.)	shallow waters	sand, stones, coral reefs

Table 4.2. continued**: Overview of size, depth distribution and habitat in native range of non-indigenous marine brachyuran decapods worldwide.**

Family	Species (underlined if established in a location)	Common size or max. size	Depth distribution	Habitat
Dorippidae	*Dorippe quadridens*	CL 4.2 cm, females 3.6 cm	intertidal to 73 m, mostly to 30 m	sandy, muddy or gravelly bottom, but also on coral reefs and oyster banks
Menippidae	*Sphaerozius nitidus*	CL 1.3 cm	intertidal	in rock crevices, on oil platform
Euryplacidae	*Eucrate crenata*	CL 3.5 cm (max.)	10-100 m	sandy, muddy bottoms.
Leucosiidae	*Ixa monodi*	CL 3.5 cm	14-60 m	sandy-mud bottom
Leucosiidae	*Coleusia signata*	CL 2.5 cm (max)	subtidal to 22 m	muddy and sandy gravel bottoms, with *Halophila*
Leucosiidae	*Myra subgranulata*	CL 4 cm	8-150 m	on sandy, muddy bottoms
M - Epialtidae	*Herbstia nitida*	CL 1.3 cm (max.)	intertidal to 73 m	rough bottom, on rock, coral, calcareous algae. Mediterranean record from a submarine cave.
M - Epialtidae	*Hyastenus hilgendorfi*	CL 3.6 cm	2-93 m	coarse sand, shell gravel, clay
M - Epialtidae	*Libinia dubia*	CL males 10 cm, fem 7.5 cm (max)	5-25 m	among algae and seaweed
M - Epialtidae	*Menaethius monoceros*	CL 2.7 cm (max.)	subtidal	rocky or sandy subtidal, on reef, among seaweeds or *Sargassum*
M - Inachoididae	*Pyromaia tuberculata*	CW males 1.8 cm, fem 1.5 cm	intertidal to 650 m	under rocks in bays, sub-littoral on protected wharf pilings, sandy or muddy bottoms

Table 4.2. continued**: Overview of size, depth distribution and habitat in native range of non-indigenous marine brachyuran decapods worldwide.**

Family	Species (underlined if established in a location)	Common size or max. size	Depth distribution	Habitat
M - Majidae	*Micippa thalia*	CL 4 cm	2-100 m	sandy, muddy, gravel, shell grit bottoms, among stones
M - Oregoniidae	*Hyas araneus*	CL 6 cm (up to 10.5 cm)	lower intertidal to 50 m (up to 555 m)	rocky, muddy and sandy bottoms
P - Galenidae	*Halimede tyche*	CL 2.2 cm (max)	2-60 m	sandy bottoms
P - Pilumnidae	*Actumnus globulus*	CL 1.4 cm (max)	?	unknown
P - Pilumnidae	*Glabropilumnus laevis*	CL 0.8 cm (max)	?	sand, stones
P - Pilumnidae	*Pilumnopeus vauquelini*	CL 1 cm	0-3 m	sandy mud, mixed with gravel and stones, or among, *Halophila*, *Sargassum*, and rich vegetation
P - Pilumnidae	*Pilumnus minutus*	CL 1 cm	20-33 m	stony, *Caulerpa* and *Hilmeda* bottom, shell, gravel
Portunidae	*Callinectes danae*	CL males 5.8 cm (max), CW 14 (max), fem CL 4.8 cm	to 75 m	muddy estuaries, mangroves, open coast, hyper-saline lagoons
Portunidae	*Callinectes sapidus*	males CL 9 cm (max), CW 20 cm (max), fem CL 7.5 cm (max)	intertidal to 90 m	estuaries and shallow coastal waters

Table 4.2. continued**: Overview of size, depth distribution and habitat in native range of non-indigenous marine brachyuran decapods worldwide.**

Family	**Species** (underlined if established in a location)	**Common size or max. size**	**Depth distribution**	**Habitat**
Portunidae	_**Carcinus aestuarii**_	CW 6 cm	intertidal to 10 m (up to 26 m)	estuarine and shallow coastal waters; muddy sand, among sea grass, under stones, typically in sheltered habitats
Portunidae	_**Carcinus maenas**_	CW 10 cm (max)	common intertidal to 6 m, but to 60 m	sandy to rocky bottoms, estuarine to marine habitats
Portunidae	_**Carupa tenuipes**_	CL 4.2 cm (max)	intertidal - 80 m	among coral reef, coral rubble, rocky bottoms
Portunidae	_**Charybdis feriata**_	CL 11 cm (max), CW 20 cm (max.)	usually subtidal, 10-60 m	mostly on sandy or muddy areas, occasionally in rocky areas, or on coral reef flats
Portunidae	_**Charybdis hellerii**_	CW male 8 cm (max.), ovigerous fem from 4.7 cm	intertidal - 50 m	prefers soft bottom, but also among rocks and live corals
Portunidae	_**Charybdis japonica**_	CW 12 cm	subtidal	eelgrass, estuarine and marine
Portunidae	_**Charybdis longicollis**_	males CL 3 cm, fem CL 2.5	10-80 m	sandy to muddy bottom
Portunidae	_**Liocarcinus navigator**_	CW 4 cm	lower intertidal to 108 m	hard and soft bottoms
Portunidae	_**Portunus pelagicus**_	CL 7 cm, CL 6.5 cm	intertidal to 55 m	sandy or muddy substrate
Portunidae	_**Scylla serrata**_	CW 18 cm	?	muddy bottoms in brackish water in mangroves and estuaries

Table 4.2. continued**: Overview of size, depth distribution and habitat in native range of non-indigenous marine brachyuran decapods worldwide.**

Family	Species (underlined if established in a location)	Common size or max. size	Depth distribution	Habitat
Portunidae	*Thalamita gloriensis*	CL 1 cm, CW 1.7 cm	?	coral sands and seaweeds
Portunidae	*Thalamita indistincta*	CL 5 cm, CW 6 cm	intertidal to 76 m	sandy to muddy bottom
Portunidae	*Thalamita poissonii*	CL 1.8 cm (max)	0-80 m	under stones, sandy and sandy-mud bottoms, with *Posidonia*, *Caulerpa*
Pilumnoididae	*Pilumnoides inglei*	?	?	?
X - Panopeidae	*Dyspanopeus sayi*	males CL 2.5 cm (max), females 1.5 cm (max)	shallow waters	shallow brackish waters, soft bottoms with sparse stones and mussel beds
X - Panopeidae	*Rhithropanopeus harrisii*	CL 2 cm (max)	lower intertidal to 36 m	brackish waters (estuarine habitats) and lakes; sandy muddy bottoms with stones or oysters
X - Xanthidae	*Atergatis roseus*	CL 6 cm	0-12 m	rock and rubble
G - Grapsidae	*Grapsus granulosus*	males CL 1.8 cm & 2.3 cm	intertidal	rocky intertidal
G - Plagusiidae	*Percnon gibbesi*	CL 3 cm	shallow subtidal (1-2 m)	between rocks
G - Plagusiidae	*Plagusia squamosa*	male CL 4.5 cm	intertidal	among stones, corals, known to attach itself to floating timber and the hull of ships

Table 4.2. continued**: Overview of size, depth distribution and habitat in native range of non-indigenous marine brachyuran decapods worldwide.**

Family	Species (underlined if established in a location)	Common size or max. size	Depth distribution	Habitat
G - Sesarmidae	*Nanosesarma minutum*	?	intertidal and subtidal	estuarine, associated with oyster bed
G - Varunidae	*Eriocheir sinensis*	CL 6.2 cm (max)	shallow waters	rivers, estuaries, lagoons, coastal regions
G - Varunidae	*Hemigrapsus penicillatus**	?	mid to low intertidal, occasionally subtidal	among rocks / cobbles and soft sediment
G - Varunidae	*Hemigrapsus sanguineus*	CL 3 cm	intertidal, sometimes subtidal	rocky bottoms
G - Varunidae	*Hemigrapsus takanoi**	CW 2 cm (up to 2.5 cm)	mid to low intertidal, occasionally subtidal (up to 20 m)	among rocks / cobbles and soft sediment
Macrophthalmidae	*Macrophthalmus graeffei*	CL males 1.1 cm, females 1.3 cm	5-74 m	fine sand with little mud

Table 4.3. Non-indigenous marine brachyuran species in the main oceanic regions and some seas. Established species are underlined.

Oceanic region	n	non-indigenous marine brachyuran species
Arctic ocean	0	-
North Sea	6-7	*Callinectes sapidus*, *Eriocheir sinensis*, *Hemigrapsus penicillatus?*, *Hemigrapsus takanoi*, *Hemigrapsus sanguineus*, *Pilumnoides inglei*, *Rhithropanopeus harrisii*
Baltic	3	*Callinectes sapidus*, *Eriocheir sinensis*, *Rhithropanopeus harrisii*
Black Sea	3	*Callinectes sapidus*, *Eriocheir sinensis*, *Rhithropanopeus harrisii*
Mediterranean	42	*see Table 1*
NE Atlantic	5-6	*Callinectes sapidus*, *Eriocheir sinensis*, *Hemigrapsus penicillatus?*, *Hemigrapsus takanoi*, *Hemigrapsus sanguineus*, *Rhithropanopeus harrisii*
NW Atlantic	7-8	*C. maenas*, *Charybdis hellerii*, *Eriocheir sinensis*, *Hemigrapsus penicillatus/takanoi*, *H. sanguineus*, *Metacarcinus magister*, *Rithropanopeus harrisii*
SE Atlantic	1	*C. maenas/C. aestuarii hybrids?*
SW Atlantic	5	*Carcinus maenas*, *Charybdis helleri*, *Liocarcinus navigator*, *Pyromaia tuberculata*, *Scylla serrata*,
NE Pacific	2	*Carcinus maenas*, *Rhithropanopeus harrisii*
NW Pacific	7	*Callinectes sapidus*, *Carcinus aestuarii*, *Carcinus maenas*, *Metacarcinus magister*, *Nanosesarma minutum*, *Pyromaia tuberculata*, *Scylla serrata*
SE Pacific	0	
SW Pacific	6	*Carcinus maenas*, *Charybdis japonica*, *Glebocarcinus amphioetus*, *Metacarcinus novaezelandiae*, *Pyromaia tuberculata*, *Romaleon gibbosulum*
Indian	1	*Carcinus maenas*
Southern Ocean	1	*Hyas araneus*

Non-indigenous brachyuran species worldwide

Listed below are the 57 non-indigenous marine brachyuran species in their respective taxonomic family following Ng *et al.* (2008) classification. For each species, information is provided on distribution (native and non-native, invasion history), habitat, biology, possible impact, general and New Zealand invasion potential, and key references.

In several cases only limited data on biology and impact were available. This list is therefore an introduction to currently available information and references and should be further developed as more information becomes available.

Section Podotremata
DROMIOIDEA

DROMIIDAE (sponge crabs)

Sternodromia spinirostris

Sternodromia spinirostris (Miers, 1881) (synonym *Dromia spinirostris*)
Distribution: native: tropical & subtropical East Atlantic; non-native: Mediterranean Sea. Single record from Italy (Pastore 1976 as cited in CIESM).
Habitat: 8–108 m depth; sand, mud bottoms
Biology: no details available
Impact: no details available
General invasion potential and in New Zealand: no details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

RANINOIDEA

RANINIDAE (frog crabs)

Notopus dorsipes

Notopus dorsipes (Linnaeus, 1758)
Distribution: native: Indo West Pacific, Red Sea to Malay Archipelago; non-native: Mediterranean Sea. Single record from Israel (Lewinsohn & Holthuis 1964 as cited in CIESM).
Habitat: 50–100 m; sandy bottoms
Biology: no details available
Impact: no details available
General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Section Eubrachyura
Subsection Heterotremata
CALAPPOIDEA

CALAPPIDAE (box crabs)

Calappa hepatica

Calappa hepatica (Linnaeus, 1758)
Distribution: <u>native</u>: IP, Red Sea to Hawaii, Clipperton Island; <u>non-native</u>: Mediterranean Sea. Only in Turkey and rare (Balkis & Çeviker 2003 as cited in CIESM).
Habitat: intertidal to 100 m; sandy muddy or gravel bottoms
Biology: no details available
Impact: no details available
General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Calappa pelii

Calappa pelii Herklots, 1851
Distribution: <u>native</u>: tropical? East Atlantic; <u>non-native</u>: Mediterranean Sea. First recorded in 1991 in Alborean Sea (CIESM) then in Italy (Pastore 1996). Established.
Habitat: 20–400 m, mostly between 50–150 m; muddy bottoms
Biology: no details available
Impact: no details available
General invasion potential and in New Zealand: no details available
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Cryptosoma cristatum

Cryptosoma cristatum Brullé, 1837
Distribution: <u>native</u>: tropical East Atlantic; <u>non-native</u>: Mediterranean Sea. Single record in Spain in 1987 (Garcia-Raso 1993 as cited in CIESM).
Habitat: intertidal to 75 m; sandy or coralligenous bottoms
Biology: Ovigerous females found during most of the year (i.e., in March, May, August, October and December) in its native range (CIESM).
Impact: no details available
General invasion potential and in New Zealand: no details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

MATUTIDAE (matutine crabs)

Ashtoret lunaris

Ashtoret lunaris (Forskål, 1775)
Distribution: <u>native</u>: Indo West Pacific, Red Sea to Australia; <u>non-native</u>: Mediterranean Sea. Single record from Israel in 1987 (Galil & Golani 1990 as cited in CIESM).
Habitat: subtidal; sandy, muddy-sand
Biology: no details available
Impact: no details available
General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

CANCROIDEA

CANCRIDAE

Glebocarcinus amphioetus

Glebocarcinus amphioetus (Rathbun 1898) big tooth rock crab
Distribution:
a) native: in the North-West Pacific; East China Sea, Yellow Sea and Sea of Japan, including Japan, Korea, and northern China (Shandong Pen and Gulf of Bohai) (Nation 1976). Common in Japan where it is recorded from the entire coasts around Hokkaido, Honshu, and Kyushu (e.g. Nations 1976; Takeda & Hyashi 1990; Komai *et al.* 1992; Kamita 1963 Miyadi 1940). In addition, it occurs from La Jolla, California to Gulf of California, Mexico, but only occasionally collected in southern California (Sandoval & Bravo 1992).
b) non-native: North and South Island of New Zealand. Crabs were found during port base line surveys on pile scrape samples. Overall few specimens (n = 4) were found in January 2003: one in Gisborne (North Island) and three in Bluff (South Island) (Inglis *et al.* 2005, 2006a). Crab size ranged between 12 and 21.8 mm carapace width (pers. obs.) and span over two size classes. It is most likely that these species arrived amongst fouling on the hulls of Asian fishing vessels employed in the New Zealand EEZ, which frequent these ports (McLay 2004, Inglis *et al.* 2005, 2006 a). None were found subsequently despite targeted intensive collections efforts (A. Brockerhoff pers. observ.).
Habitat: often in weedy beaches near the low tide mark, rocky beaches, intertidal – 65 m deep (Sakai 1976, Ai-Yun & Si-Liang 1991). Among mostly sandy and partially rocky bottom in the intertidal (Brockerhoff pers. observ). Also reported from deeper water of 25–125 m depth in trawls taken from the continental shelf in the Gulf of California (Hendrickx 1996 as cited in Inglis *et al.* 2005) and of 200 to 260 m depth in Taiwan (Wei-Rung *et al.* 1999 as cited in Inglis *et al.* 2006a).
Biology: An ovigerous female was collected in the intertidal of southern Hokkaido (Iwata & Konishi 1981). As in other Cancridae, larval development of *Glebocarcinus amphioetus* includes a pre-zoea, 5 zoeal instars and a megalopa and their morphology (except pre-zoea) has been described in detail by Iwata & Konishi (1981). Juvenile crabs are highly variable in colouration, from uniformly white to deep red, brownish, purple, blue or green colours on their carapace and legs. Various colours can also occur in bands or stripes on the juvenile crab (Sakai 1976). An average of 0.21 crabs per square metre were found during a study on distribution patterns of benthic invertebrates in algal communities in a rocky sub littoral area of down to 7 m depth of Northern Japan (Omori *et al.* 2000). A male was found in 15 m depth in eastern Hokkaido (Takeda & Hayashi 1990). Overall, little is known about the biology and ecology of this crab even though it is apparently fairly common and widely distributed in its native range.
Impact: No impact has been demonstrated as few specimens were found in New Zealand. However, considering that it can be a very common crab in its native range it would probably have some effect on local fauna and flora through competition for food and habitat.
General invasion potential and in New Zealand: As little is known about the ecology of this species from its native range its invasion potential in general and for New Zealand are difficult to predict. From the information available, we known that this species occupies a large range of habitats (from sandy, weedy to rocky bottom), occurs over a large depth range (intertidal to 260 m), and its range includes various temperature regimes (Gulf of California to Sea of Japan). *Glebocarcinus amphioetus* would therefore be well prepared to invade a number of habitats in an exotic environment such as New Zealand.

Metacarcinus magister

Metacarcinus magister (Dana, 1852) Dungeness crab

Distribution: a) <u>native</u>: North-East Pacific; b) <u>non-native</u>: Japan (North-West Pacific), Massachusetts (North-West Atlantic). In Japan, a single large male was collected outside its natural range in 1979 by a beam trawl from 15 m depth in the Pacific coast of eastern Hokkaido (Abe 1981). It was speculated that the crab might have migrated from north-western coast of America (Alaska) along with a cold northern current, as similarly some unusual reports of Alaskan flounder near Hokkaido have been made, or alternatively the crab arrived via ballast water (Abe 1981). In Massachusetts, a single large male crab was caught in 2006 off the coast Massachusetts, it was speculated that it may have been purchased from a live seafood marked and then released (Wilbur 2006).

Habitat: intertidal to 107 m; eelgrass, sandy shelly bottoms

Biology: Ovigerous female *Metacarcinus magister* aggregate during winter and early spring in water deeper than 16 m. In April, when spring phytoplankton bloom occurs, ovigerous females move into shallow water where larval hatching starts to occur. In July, females move back into deeper water. This movement into shallow water during the period of larval hatching is in contrast to the offshore movement reported for ovigerous females in northern California and Washington. Reasons for the shore movement might be the phytoplankton bloom, accelerated embryo development in warmer, highly oxygenated water and possibly to retain hatched larvae within the bay. Bald eagles, north-western crows and several species of gulls have been seen preying on the crabs in the shallow water (Stone & O'Clair 2002). The non-indigenous *Carcinus maenas* appears to experience some biotic resistance by adult *M. magister* (Hunt & Yamada 2003), but juvenile *M. magister* may emigrate from refuge habitats as a result of competition and predation by adult *C. maenas* (McDonald *et al.* 2001). Therefore, *C. maenas* can potentially negatively influence juvenile *M. magister* survival, and subsequently, recruitment to the fishery. The extent to which these two species overlap will determine the full impact of *C. maenas* on *M. magister* (McDonald *et al.* 2001).

Impact: No details available.

General invasion potential and in New Zealand: No details available.

Metacarcinus novaezelandiae

Metacarcinus novaezelandiae (Hombron & Jaquinot, 1846) **Pie-crust crab**

Distribution: <u>native</u>: New Zealand (South West Pacific); <u>non-native</u>: Australia (Tasmania, Victoria, New South Wales) (Poore 2004). Invasion history: First recorded in about 1930 from Hobart harbour (where it is now common around eastern Tasmania) and Port Phillip Bay (where it has not been found since). In 1991, a single specimen was collected by a fisherman in the Gippsland Lakes, Victoria. Since at least 1995, a local population has resided on Flinders Reef, Victoria. There are also a few records from other locations in Victoria such as Bass Strait. In Eden, New South Wales (Poore 2004).
    This crab apparently arrived in Tasmania accidentally as part of a shipment of oysters from New Zealand, brought in to establish an oyster fishery. Other molluscs were also accidentally transported and several of these have become nuisance species.

Habitat: low intertidal to subtidal; sand bottom, under stones and among large seaweeds

Biology: *M. novaezelandiae* is a benthic crab which burrows amongst sand to hide itself. The diet comprises of predominantly sessile and slow-moving macro-invertebrates such as bivalves and gastropod molluscs, followed by crustaceans, and also includes fish,

sponges, coelenterates, and plant matter (Creswell & Marsden 1990). *M. novaezelandiae* can easily open cockle and oyster shells.

Impact: In Australia, potential impacts may include economic (loss of aquaculture, commercial or recreational harvest) and environmental (dominates or out competes and limits resources of native species or predation of native species) impacts (Hayes *et al.* 2005).

General invasion potential and in New Zealand: endemic in New Zealand.

Romaleon gibbosulum

Romaleon gibbosulum (De Haan, 1833)

Distribution: a) <u>native</u>: Japan, coast of Korea to Northern China (Liaodong Pen) (Sakai 1976, Ai-Yun & Si-Liang 1991). In Japan, *R. gibbosulum* occurs around the entire coast around Honshu, Shikoku and Kyushu (Sakai 1976), as well as around northern and southern Hokkaido (Komai *et al.* 1992, Honma & Muraoka 1992); b) <u>non-native</u>: North and South Island of New Zealand. <u>Invasion history</u>: Crabs were found during port base line surveys on pile scrape samples. Overall few specimens (n = 5) were found in November 2001: one in Wellington (North Island), one in Lyttelton and three in Timaru (South Island) (Inglis *et al.* 2006 b, c, d). Crab size ranged between 7 – 23.5 mm carapace width (pers. obs.) and span over two size classes. It is most likely that these species arrived amongst fouling on the hulls of Asian fishing vessels employed in the NZ EEZ, which frequent these ports (McLay 2004, Inglis *et al.* 2006 b, c, d). None were found subsequently despite targeted intensive collections efforts (Brockerhoff pers. observ.).

Habitat: 30–100 m deep (Sakai 1976), 33–238 m (Yokoya 1933). Muddy-sandy or broken shelly and sandy bottoms (Sakai 1976, Ai-Yun & Si-Liang 1991). Male crabs in 30 m deep waters of Niigata, Sea of Japan (Ito & Honma 2001). Crabs were found among tube-forming annelids and their empty tubes (*Lygdamis*) in sandy, gravely bottoms (Miyadi 1940).

Biology: *R. gibbosulum* is one of the dominant mega-benthos species in Ise Bay, Central Japan and ranked ninth in biomass and tenth in abundance of the mega benthos collected (Narita *et al.* 2003). During a seven year study from 1993 to 1999 almost 9,000 specimens were collected at 18 stations using a bottom dredge. *Romaleon gibbosulum* abundance and biomass showed strong seasonal and inter-annual variations with population densities typically decreasing from summer to autumn and increasing from winter to spring or summer. The highest number of crabs was found in June 1997 when about 2,600 crabs were caught. The inter-annual variation and spatial distribution of species abundance in Ise Bay appear to be linked to the oxygen content in the water, e.g. decreasing abundance and biomass with decreasing oxygen content and larval recruitment (Narita *et al.* 2003). *R. gibbosulum* feeds on a range of prey in Ise Bay which typically includes crustaceans and polychaetes and occasionally ophiuroids, bivalves and gastropods. A large proportion of food items were unidentifiable (Narita & Sekiguchi 2002). The morphology of zoeae has been described by Terada (1987). The carapace width of the smallest ovigerous female was 22.2 mm and of the smallest mature male was 20.8 mm among collections in Japanese museums (Brockerhoff pers. observ.).

Impact: No impact has been demonstrated as few specimens were found in New Zealand. However, considering that it can be a very common and widely distributed crab in its native range it would probably have some effect on local fauna and flora through competition for food and habitat.

General invasion potential and in New Zealand: As little is known about the ecology of this species from its native range, its invasion potential in general, and for New Zealand, is difficult to predict. From the information available, we know that this species occupies

a large range of habitats (from muddy-sandy to broken shelly bottoms), occurs over a large depth range (30 to 238 m), and its range includes various temperature regimes (Japan, Korea to North China). *Romaleon gibbosulum* would therefore be well prepared to invade a number of habitats in an exotic environment and could do well in New Zealand.

DAIROIDEA

DAIRIDAE

Daira perlata

Daira perlata (Herbst, 1790)
Distribution: <u>native</u>: Indo West Pacific; <u>non-native</u>: Mediterranean Sea. Single record from Turkey in 1988 (Enzenroß & Enzenroß 1995 as cited in CIESM).
Habitat: shallow waters; sand, stones, coral reefs
Biology: no details available
Impact: no details available
General invasion potential and in New Zealand: no details available. Unlikely to invade New Zealand as Suez Canal was vector.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

DORIPPOIDEA

DORIPPIDAE

Dorippe quadridens

Dorippe quadridens (Fabricius, 1793)
Distribution: <u>native</u>: Australia, China, East Africa, Red Sea (Holthuis & Manning 1990 in Galil 2005); <u>non-native</u>: Mediterranean Sea. Common along the central coast of Israel (Galil 2005).
Habitat: intertidal to 73 m, mostly to 30 m, sandy, muddy or gravelly bottom, but also on coral reefs and oyster banks.
Biology: no details available
Impact: no details available
General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

ERIPHIOIDEA

MENIPPIDAE

Sphaerozius nitidus

Sphaerozius nitidus Stimpson, 1858
Distribution: <u>native</u>: Indo West Pacific; <u>non-native</u>: Mediterranean Sea. Single record from Egypt (Ramadan & Dowidar 1976 as cited in CIESM).
Habitat: intertidal, in rock crevices, on oil platform
Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

GONEPLACOIDEA

EURYPLACIDAE

Eucrate crenata

Eucrate crenata (de Haan, 1835)

Distribution: <u>native</u>: Indo Pacific (Red Sea to Hawaii); <u>non-native</u>: Mediterranean Sea. First recorded in Egypt 1924, and then from Turkey in 1992, Tunisia 1993 and Israel 1997 (CIESM). Established and locally common.

Habitat: 10–100 m, sandy, muddy bottoms.

Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

LEUCODIOIDEA

LEUCOSIIDAE (pebble crabs)

Ixa monodi

Ixa monodi Holthuis and Gottlieb, 1956

Distribution: <u>native</u>: Red Sea; <u>non-native</u>: Mediterranean Sea. First record from Turkey in 1955, then from Israel (Golani *et al.* 1983) and Greece (Galil & Kevrekidis 2002) (as cited in CIESM). Common along the coast of Israel.

Habitat: 14–60 m, sandy-mud bottom

Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Coleusea signata

Coleusea signata (Paulson, 1875) ***(formerly Leucosia signata)***

Distribution: <u>native</u>: Indo West Pacific; <u>non-native</u>: Mediterranean Sea. First recorded from Israel in 1953 (Holthuis 1956) and then in Egypt (Ramadan & Dowidar 1976), Lebanon (Shiber 1981), and Turkey in 1976 (Grippa 1982). (as cited in CIESM). Established, but rare.

Habitat: subtidal to 22 m, muddy and sandy gravel bottoms, with *Halophila*.

Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Myra subgranulata

Myra subgranulata Kossmann, 1877

Distribution: <u>native</u>: West Indian Ocean (Red Sea to Madagascar); <u>non-native</u>: Mediterranean Sea. First recorded from Palestine in 1929 (Monod 1930), then from Turkey (Monod 1930), Egypt (Balss 1936) and Lebanon (Shiber 1981). (as cited in CIESM). Abundant along the coast of Israel.

Habitat: 8–150 m, on sandy, muddy bottoms.

Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

MAJOIDEA

EPIALTIDAE

Herbstia nitida

Herbstia nitida Manning and Holthuis, 1981

Distribution: <u>native</u>: tropical East Atlantic (Gulf of Guinea); <u>non-native</u>: Mediterranean Sea. First recorded from Italy and included juveniles and adults (CIESM). Established, small local populations.

Habitat: intertidal to 73 m, rough bottom, on rock, coral, calcareous algae. Mediterranean record from a submarine cave.

Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Hyastenus hilgendorfi

Hyastenus hilgendorfi De Man, 1887

Distribution: <u>native</u>: Indo West Pacific (Red Sea to Malay Archipelago); <u>non-native</u>: Mediterranean Sea. First recorded from Israel in 1940 (Lewinsohn & Holthuis 1964) and then Egypt (Ramadan & Dowidar 1976). (as cited in CIESM). Was originally described as established but rare (CIESM), but now considered by some as possibly casual records without established populations (Zenetos *et al.*2005).

Habitat: 2–93 m, coarse sand, shell gravel, clay

Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Libinia dubia

Libinia dubia H. Milne Edwards, 1834
Distribution: <u>native</u>: West Atlantic (from Massachusetts to Cuba); <u>non-native</u>: Mediterranean Sea. Common in Tunisia (Enzenroß *et al.*1997 as cited in CIESM). Established.
Habitat: 5–25 m, among algae and seaweed.
Biology: Juveniles associated with and feeding upon scyphomedusae. Adult benthic.
Impact: no details available
General invasion potential and in New Zealand: no details available
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Menaethius monoceros

Menaethius monoceros (Latreille, 1825)
Distribution: <u>native</u>: Indo-Pacific (Red Sea to Hawaii and Tahiti); <u>non-native</u>: Mediterranean Sea. Single record from Italy in 1978 (CIESM).
Habitat: subtidal; rocky or sandy bottom, on reef, among seaweeds or *Sargassum*
Biology: no details available
Impact: no details available
General invasion potential and in New Zealand: no details available
References: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

INACHOIDIDAE

Pyromaia tuberculata

Pyromaia tuberculata (Lockington, 1877)
Distribution: native: Gulf of California to Panama (N E Pacific); non-native distribution: Brazil, Argentina, Japan (Sakai 1971; Asakura 1992), Australia, New Zealand; invasion history: In Japan, *Pyromaia tuberculata* was first recorded in 1970 in Tokyo Bay and is now distributed along the Pacific coast of central Japan, eastern part of Seto Inland Sea, and the Sea of Japan off Honshu (Furota & Furuse 1988). In Australia *Pyromaia tuberculata* was first collected in Western Australia in 1978 and has since been recorded from southern (Port Phillip Bay) and eastern (New South Wales) Australia (Ahyong 2005). In New Zealand first recorded in 1978 in Firth of Thames (Auckland) (Webber & Wear 1981). Established in all countries listed.
Habitat: Under rocks, among sponges and sea weed on wharf piles, on sand and mud, intertidal to 650 m.
Biology: In Japan, *P. tuberculata* is abundant in organically polluted, large shallow bays such as Tokyo Bay, Osaka Bay, Sagami Bay and Ise Bay from the intertidal down to 80 metres (Furota & Furuse 1988, Sakai 1976). In Tokyo Bay *Pyromaia tuberculata* is abundant and sustains significant population densities in the Bay despite large scale bottom hypoxia in summer. Adult crabs perish due to oxygen deficiency in late summer in the inner harbour, but fast re-colonisation of the oxygen recovered bottom in autumn, from crabs from the outer half of the bay, maintains the inner harbour population (Furota 1990, 1996 a, b; Furota & Kinoshita 2004). In New Zealand ovigerous crabs have been collected in the winter months from April to August, whereas in Southern California ovigerous females occur over most the year with a peak in the summer months (McLay 1988).
Impact: No details available.
General invasion potential and in New Zealand: *P. tuberculata* is abundant throughout New Zealand.

MAJIDAE (spider crabs)

Micippa thalia

Micippa thalia (Herbst, 1803)

Distribution: <u>native</u>: Indo West Pacific; <u>non-native</u>: Mediterranean Sea. First recorded from Turkey in 1994 (Enzenroß & Enzenroß 1995 as cited in CIESM), then from Lebanon in 1999 and Turkey 2003 (CIESM). Established, but rare.

Habitat: 2-100 m, sandy, muddy, gravel, shell grit bottoms, among stones.

Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

OREGONIIDAE

Hyas araneus

Hyas araneus (Linnaeus, 1758)

Distribution: <u>native</u>: North Atlantic (from Iceland, Spitzbergen and European Russia to the English Channel); <u>non-native</u>: Southern Ocean. Single record from Antarctic Peninsula (Tavares *et al.* 2004).

Habitat: lower intertidal to 50 m (up to 555 m), rocky, muddy and sandy bottoms.

Biology:

Impact: no details available

General invasion potential and in New Zealand: no details available

Key reference: Tavares *et al.* 2004

PILUMNOIDEA

GALENIDAE

Halimede tyche

Halimede tyche (Herbst, 1801)

Distribution: <u>native</u>: Indo West Pacific (Persian Gulf to Australia); <u>non-native</u>: Mediterranean Sea. Single record from Israel in 1998 (Galil 2000).

Habitat: 2-60 m, sandy bottoms.

Biology: no details available

Impact: no details available

General invasion potential and in New Zealand: no details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

PILUMINIDAE (bristle crabs)

Actumnus globulus

Actumnus globulus Heller, 1861
Distribution: <u>native</u>: Red Sea, West Indian Ocean; <u>non-native</u>: Mediterranean Sea. Single record only (Galil *et al.* 2006).
Habitat: No details available.
Biology: No details available
Impact: No details available
General invasion potential and in New Zealand: No details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Glabropilumnus laevis

Glabropilumnus laevis (Dana, 1852) **(formerly *Heteropanope laevis*)**
Distribution: <u>native</u>: Indian Ocean; <u>non-native</u>: Mediterranean Sea. Was seen as established (CIESM), but now more as casual records without established populations (Zenetos *et al.* 2005).
Habitat: sand, stones
Biology: No details available
Impact: No details available
General invasion potential and in New Zealand: No details available. Unlikely to invade via same vector in New Zealand as Suez Canal was vector.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Pilumnopeus vauquelini

Pilumnopeus vauquelini (Audouin, 1826)
Distribution: <u>native</u>: Red Sea, Persian Gulf; <u>non-native</u>: Mediterranean Sea. First reported in Egypt in 1924 (Calman 1927) and then in Israel (Holthuis 1956) and Turkey (Kocatas 1981) (as cited in CIESM). Established, but rare.
Habitat: 0-3 m, sandy mud, mixed with gravel and stones, or among *Halophila*, *Sargassum*, and rich vegetation
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available. Unlikely to invade New Zealand as Suez Canal was vector.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Pilumnus minutus

Pilumnus minutus De Haan, 1835 *(formerly Pilumnus hirsutus)*
Distribution: <u>native</u>: Indo West Pacific; <u>non-native</u>: Mediterranean Sea. Single record from Egypt (Balss 1936 as cited in CIESM). Found in a ship's sea chests in Nelson, New Zealand (Taylor 2004, Cawthron press release).
Habitat: 20-33 m, stony, *Caulerpa* and *Halimeda* bottom, shell, gravel.
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

PORTUNOIDEA

PORTUNIDAE (swimming crabs)

Callinectes danae

Callinectes danae Smith, 1869
Distribution: <u>native</u>: North to South West Atlantic (from North Carolina to Brazil); <u>non-native</u>: Mediterranean Sea, Japan (unknown status). In Mediterranean known from single record in Italy in 1981 (Mizzan 1993 as cited in CIESM).
Habitat: to 75 m, muddy estuaries, mangroves, open coast, hypersaline lagoons.
Biology: Appears to spawn throughout the year (Williams 1984).
Impact: No details available.
General invasion potential and in New Zealand: No details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Callinectes sapidus

Callinectes sapidus Rathbun, 1896 **Blue crab**
Distribution: <u>native</u>: North and South West Atlantic (from Nova Scotia to Uruguay); <u>non-native</u>: North-East Atlantic, Baltic, Black Sea, Mediterranean, North Sea (Netherlands, Germany); North-West Pacific (Japan 1974), Hawaii. Established in most listed locations.
Callinectes sapidus has been recorded from Japan a few times since 1975 (Muraoka & Taguchi 1992)) and been observed in Hawaii since 1985 (Eldredge 1995). It was most likely introduced with ballast water and possibly also through hull fouling. It has been reported from Danish waters but has not become established yet (Jensen & Knudsen 2005). Population in Greece declining possibly due to over fishing (CIESM).
Habitat: intertidal to 90 m, estuaries and shallow coastal waters.
Biology: *Callinectes sapidus* is tolerant to a wide range of temperature and salinities (eurythermal and euryhaline). It is highly fecund and omnivorous (e.g. clams, mussels and oysters).
Uses: *Callinectes sapidus* is an important commercially fished species in its native range (Atlantic coast of North America south to Uruguay) and also some locations in its introduced range (e.g. Northern Sinai) (see Hayes & Sliwa 2003).
Impact: *Callinectes sapidus* has been reported to feed on fish caught in traps and to damage nets (CIESM 2008) and readily feeds on clams, mussels and oysters. Potential impact may therefore include some loss of aquaculture, commercial, or recreational harvest.
General invasion potential and in New Zealand: It has been suggested that *Callinectes sapidus* is a successful invader because it is eurythermal and euryhaline, highly fecund, aggressive and a good swimmer (CIESM).
Key reference: Hayes & Sliwa 2003; CIESM 2008 Atlas of exotic crustaceans in the Mediterranean

Carcinus aestuarii

Carcinus aestuarii Nardo, 1847 **Mediterranean green crab**

Distribution: <u>native</u>: Mediterranean; <u>non-native</u>: Japan (since 1984): Tokyo Bay, Osaka Bay, Katsuura River (Tokushima) (Kimura *et al.* 2004). Possibly hybrid of *C. maenas* and *C. aestuarii* in Japan and South Africa (Carlton *et al.* 2003).

Habitat: intertidal to 10 m (up to 26 m), estuarine and shallow coastal waters; muddy sand, among seagrass, under stones, typically in sheltered habitats

Biology: In Japan, *Carcinus aestuarii* occurs abundantly in the organically polluted water in Tokyo Bay and its seasonal migratory patterns allow the exotic crab to avoid bottom hypoxia in summer by migrating to near shore areas and therefore to maintain high population densities (Furota *et al.* 1999; Furota & Kinoshita 2004).

Impact: could be similar to *Carcinus maenas* but less is known on the ecological impact of *C. aestuarii* to estimate their impact (Carlton *et al.* 2003).

General invasion potential and in New Zealand: appears to be able to tolerate slightly warmer regions than *C. maenas* but less is known on the physiological tolerance of *C. aestuarii* to estimate their exact potential range (Carlton *et al.* 2003).

Carcinus maenas

Carcinus maenas (Linnaeus, 1758) **European shore crab or green crab**

Distribution: <u>native</u>: East Atlantic (North-Western Europe and northern Africa), North Sea, Baltic; <u>non-native</u>: North and South West Atlantic (USA, Argentina), South Africa (Cape Town), North and South Pacific (USA, Australia). Invasion history: First recorded in 1817 in Massachusetts; in 1989 in San Francisco Bay, California; in the late 19th century in southern Australia (Port Philip Bay); in 1983 in South Africa; in 2003 in Argentina. (Klassen & Locke 2007).
Many vectors have played a role in distributing *C. maenas* around the world. Originally dry ballast and fouling on ship hulls played a major role, and then dominantly ballast water and others such as drilling platforms and fishery product transport. Then secondary local dispersal occurred through natural dispersal and water currents (Klassen & Locke 2007).

Habitat: common intertidal to 6 m (i.e., upper intertidal to shallow subtidal), but to 60 m, sandy to rocky bottoms, estuarine to marine habitats (euryhaline).

Biology: *Carcinus maenas* is a food generalist and feeds on a vast amount of different organisms including plants, protists and animal phyla which encompass about 100 families and 158 genera. The most common prey items are mussels, clams, snails, polychaetes, crabs, isopods, barnacles and algae. *Carcinus maenas* is euryhaline and tolerates salinities from 4 to 53º/oo. *Carcinus maenas* is also eurythermic and survives in temperatures ranging from 0-35ºC, but need temperatures between 18–26ºC to reproduce. Females lay up to 185,000 eggs per clutch. Larval stages include a protozoea, 4 stages of zoea and the megalopa. Green crab live up to 4–7 years, with females typically living for about 3 years and males about 5 years.

Impact: competition for food and habitat can cause decline of other crab and bivalve species including mussel farm species. Impacts on prey populations seem to be greater in soft-bottom habitat and in sheltered habitats protected from strong wave actions.

General invasion potential and in New Zealand: *Carcinus maenas* is one of the most invasive brachyuran crabs worldwide and has a proven record of being highly invasive as it has successfully invaded many countries and oceans. For Australia it has been ranked as a 'medium priority species' as a domestic target species based on its reasonably high impact/or invasion potential to uninfected bioregions (Hayes *et al.* 2005). In New Zealand it could be a major threat to our green lip mussel industry.

Management: Control efforts have included a range of methods including fencing, trapping and poisoning, however, with limited effect. The potential use of biological control has

been investigated in the case of the parasitic barnacle *Sacculina carcinus*, however, because of its low host specificity and its potential to infect native Australian and North American species it is not likely to be used in the future (Thresher *et al.* 2000; Goddard *et al.* 2005). Commercial fisheries for green crabs have occasionally reduced the number of crabs in parts of its native range.

Key reference**:** Klassen & Locke 2007.

Carupa tenuipes

Carupa tenuipes Dana, 1852

Distribution: native: IP (from Red Sea to Japan, Australia, Polynesia and Hawaii); non-native: Mediterranean Sea. Records from Israel and Turkey. Established populations (Zenetos *et al.* 2005).

Habitat: intertidal - 80 m, among coral reef, coral rubble, rocky bottoms.

Biology: No details available.

Impact: No details available.

General invasion potential and in New Zealand: No details available. Unlikely to invade via same vector in New Zealand as Suez Canal was route of entry.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Charybdis (Charybdis) feriata

Charybdis (Charybdis) feriata (Linnaeus, 1758)

Distribution: native: Indo Pacific (eastern and southern Africa, Gulf of Oman and Arabian Gulf including Pakistan, India, Sri Lanka and Indonesia, from China and Japan to Australia)(see references in Abello & Hispano 2006); non-native: Mediterranean (single specimen in 2004 in Spain (Abello & Hispano 2006). It has been suggested that accidental escape from seafood holding tanks of vessels arriving from the Far East was the likely transfer vector. The specimen had a Mediterranean epibiont, the serpulid polychaete *Pomatoceros triqueter*, attached to its carapace indicating that it had spent at least some weeks in the Mediterranean waters before being caught (Abello & Hispano 2006).

Habitat: Occurs mostly on sandy or muddy areas, occasionally in rocky areas, or on coral reef flats. Single specimen in Spain was found in 60-70 m off Barcelona, Spain (Abello & Hispano 2006).

Biology: *Charybdis feriata* breeds throughout the year in southwestern Indian waters, with peaks of ovigerous females in January and February (Pillai & Nair 1976 as cited in Mantellatto & Garcia 2001). Females weigh between 150-350 g and males up to 1 kg. It is of commercial value and exported throughout East Asia. Previously mainly sold frozen, but now also maintained in aquaria and holding tanks (Abello & Hispano 2006).

Impact: No documented impacts.

General invasion potential and in New Zealand: No details available.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Charybdis (Charybdis) hellerii

36. *Charybdis (Charybdis) hellerii* (A. Milne Edwards, 1867)

Distribution: native: Indo Pacific (Japan, Philippines, New Caledonia, Australia, Hawaii, and throughout the Indian Ocean, including the Red Sea); non-native distribution: M, NW &

SW At (Florida to Brazil); invasion history: In the Mediterranean, *C. hellerii* was first recorded from Palestine about mid 1920s and subsequently from Egypt (1936), Turkey (1981), Lebanon (1981), Syria (1993) and Cyprus (1999) (see CIESM 2008). In the West Atlantic, *C. hellerii* was first reported in 1987 and 1988 in the Gulf of Mexico and the Caribbean Sea (Cuba (Gomez & Martinez-Iglesias 1990); Venezuela (Hernández & Bolaňos); and Colombia (Campos and Turkay 1989)), and then in 1995 in Florida (Lemaitre 1995) and Brazil (Tavares & De Mendonca 1996; Mantellato & Dias 1999). Some unpublished earlier records refer also to *C. hellerii* found in South Carolina in 1986 and later on in North Carolina in 2004 (USGS factsheet) (*http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=191*). *Charybdis hellerii* was found in the sea-chest of a fishing vessel in New Zealand (Dodgshun & Coutts 2004), but has so far not been detected in New Zealand waters. It has been suggested that *C. hellerii* arrived in the Mediterranean via the Suez Canal (CIESM) and to the Western Atlantic originally via ballast water or as fouling organisms and possibly subsequently spread by larval transport with local currents (Campos & Turkay 1989; Gomez & Martinez-Iglesias 1990; Tavares & De Mendonca 1996).

Habitat: intertidal - 50 m; prefers soft bottom, but also among rocks and live corals. In its native range *C. hellerii* is reported to inhabit soft bottoms, but also to occur among rocks and live corals (Stephenson *et al.* 1957). In Florida, the exotic populations are also common with structured habitats near inlets such as inter and sub-tidal coralline rock, ledges, rocks around jetties, concrete rubble and bulkheads (Dineen *et al.* 2001). In Columbia, *C. hellerii* was found among sea grass meadows and mangrove roots (Campos & Turkay 1989).

Biology: The maximum carapace width of males is about 8 cm in Malaysia (Wee & Ng 1995). Ovigerous females range in carapace width from the 4.7 cm plus in Australian (Stephenson *et al.* 1957) to a maximum of 5.4 cm in Florida (Lemaitre 1995), 5.6 cm in Colombian (Campos & Turkay 1995) to 5.7 cm in Brazil (Mantelatto & Garcia 2001). In Brazil, *C. hellerii* ovigerous females are present throughout most of the year, with peak spawning during the winter (Mantelatto & Dias 1999; Mantelatto & Garcia 2001). Fecundity of *C. hellerii* is high and ranges from 22,550 to 3,200,000 eggs per brood depending on female size (Sumpton 1990, Siddiqui & Ahmed 1992 as cited in Dineen *et al.* 2001, Lemaitre 1995). The larval period was 44 days for larvae reared in the laboratory at 24 degree Celsius (Dineen *et al.* 2001). Sexual maturity was reached at 67 mm carapace width of a single female in the laboratory which subsequently laid 6 broods within a year (Dineen *et al.* 2001). It has been suggested that the geographic range distribution of 5 species of *Charybdis* along the coast of east and west Australia is temperature regulated and that *C. hellerii* is most tolerant of lower temperatures (Stephenson *et al.* 1957). The epibiont barnacle *Chelonibia patula* was found on crabs from Pakistan (Javed & Mustaquim 1994) and a parasitic barnacle *Sacculina* sp. has been found in 1.3% of crabs in Australia (Stephenson *et al.* 1957).

Impact: unknown. *Charybdis hellerii* could potentially compete for food and habitat with native brachyuran crabs, such as the blue crab *Callinectes sapidus*, and therefore negatively impact on the blue crab fishery in certain areas.

Uses: fisheries, others. *Charybdis hellerii* is commercially important in Southeast Asia (Moosa 1981 as cited in Lemaitre 1995), but no market exists for it in the United States.

General invasion potential and in New Zealand: Over all, *C. hellerii* is more a tropical species but can tolerate relatively low temperature in comparison to five other Australian *Charybdis* species (Stephenson *et al.* 1957). It has been suggested that *C. hellerii* is a successful marine invader because of its life and natural history traits such as 1) long larval life (44 d) facilitating dispersal, 2) maturation within a year which promotes rapid population growth, 3) sperm storage and production of multiple large broods allows rapid expansion of founder populations, 4) generalized, opportunistic carnivore, allows

exploitation of a variety of food resources and 5) use of diverse habitats (Dineen *et al.* 2001). These are similar traits described for the invasive *Carcinus maenas* (Cohen *et al.* 1995; Grosholz & Ruiz 1996).

Key Reference: Dineen *et al.* 2001

Charybdis (Charybdis) japonica

Charybdis (Charybdis) japonica (A. Milne Edwards, 1861) Asian paddle crab, lady crab

Distribution: native: China, Japan, Korea, Taiwan, Malaysia (Wee & Ng 1995 in Smith *et al.* 2003); non-native: South-West Pacific (first in 2000 in New Zealand) (Gust & Inglis 2006). In New Zealand *C. japonica* is abundant in the Waitemata Harbour (Auckland) and occurs in two nearby estuaries, but have not spread to other shipping ports nationwide. It remains to be shown whether the *C. japonica* population in New Zealand is self-sustaining (Gust & Inglis 2006). A single live, mature, male specimen of *C. japonica* was also discovered by a fisherman in the Port river in Adelaide in 2000 (Anon 2001), but none have subsequently been reported. The vector of introduction in this case is unknown but ballast-water or hull-fouling are likely candidates, along with the possibility of sea chests.

Habitat: subtidal, eelgrass, estuarine and marine habitats. In its native habitat in Korea, juvenile *C. japonica* are abundant in eelgrass (*Zostera marina*) meadows (Huh and An 1998, in Smith *et al.* 2003). In New Zealand it is found in estuarine habitats with fine, silty muddy bottom to coarse, shelly sand bottom (Gust & Inglis 2006).

Biology: *Charybdis japonica* is an opportunistic predator of bivalves, fish, cephalopods and other benthic invertebrates (Jiang *et al.* 1998, in Smith *et al.* 2003). In China spawning occurs in spring and autumn when sea temperatures are between 20°C and 28°C (Wang *et al.* 1996 as cited in Gust & Inglis 2006). Females lay an average of c. 85 000 eggs per brood (Wang *et al.* 1996, Smith *et al.* 2003) and may produce multiple broods in a single year.

Uses: A commercially important species in its native range of central and South East Asia where it is trapped using pots and gill nets (Archdale *et al.* 2006).

Impact: *Charybdis japonica* is a host or carrier of the White Spot Syndrome Virus (WSSV) which can be a serious fisheries threat. WSSV infects a broad spectrum of crustaceans, and can cause cumulative mortalities of up to 100% within 3 to 10 days of the first signs of the disease. Some infected individuals do not die from the disease but are carriers that can spread the pathogen (Maeda *et al.* 1998). In New Zealand, the distribution of *C. japonica* overlaps with that of the native portunid crab *Ovalipes catharus*, but they seemed to prefer slightly different habitats. *Charybdis japonica* occupied muddy sediments in which *O. catharus* was rare. If the *C. japonica* population in New Zealand is self-sustaining and continues to spread, it is likely to have significant impacts on native estuarine benthic flora and fauna (Gust & Inglis 2006).

General invasion potential and in New Zealand: *Charybdis japonica* has been listed as a potential next pest species in Australia with the potential effect to introduce/facilitate new pathogens or parasites (Hayes & Sliwa 2003). *C. japonica* was categorized as a 'Medium High Priority' species based on its invasion potential/impact (Hayes & Sliwa 2003). The ISSG database states that it "may impact native estuarine communities by competing for space and resources with native crabs. As it transmits disease and preys on native shellfish it is a potential threat to fisheries and traditional shell-fishing." If the *C. japonica* population in New Zealand is self-sustaining and continues increase and spread, it is likely to have significant impacts on native estuarine benthic flora and fauna (Gust & Inglis 2006).

Management: We are not aware of any current programme trying to eradicate *C. japonica*. If some physical removal was contemplated, it has been shown in Japan that dome-shaped pots with open funnel entrances catch crabs better than box-shaped pot with slit entrances (100% vs. 66%, respectively) (Archdale *et al.* 2006 as cited in Gust & Inglis 2006).

Other reference: ISSG database.

Charybdis (Charybdis) longicollis

Charybdis (Charybdis) longicollis Leene, 1938

Distribution: <u>native</u>: Indo-Pacific (Red Sea, Madagascar, East Africa, Persian Gulf); <u>non-native</u>: M; invasion history: first recorded from Turkey (Holthuis 1961) and then from Israel (Lewinsohn & Holthuis 1964), Egypt (Ramadan & Dowidar 1976), Lebanon (Shiber 1981), Cyprus (Lewinsohn & Holthuis 1986), Greece (Galil & Kevrekidis 2002) (as cited in CIESM). Abundant in the Mediterranean since 1960s.

Habitat: intertidal to 55 m; sandy or muddy substrate.

Biology: The parasitic barnacle *Heterosaccus dollfusi* has also travelled through the Suez Canal and is infecting its natural host *Charybdis longicollis* now in the Mediterranean (Galil & Lützen 1995, 1998).

Impact: Often caught by trawl fisherman as seen as pests.

General invasion potential and in New Zealand:

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Liocarcinus navigator

Liocarcinus navigator (Herbst, 1794) *(syn. Polybius holsatus)*

Distribution: <u>native</u>: Eastern Atlantic, Mediterranean, Adriatic and Black Seas; <u>non-native</u>: South West Atlantic (Brazil). Recorded in samples from 1966-1969 from Brazilian coast (de Melo *et al.* 2002).

Habitat: lower intertidal to 108 m; hard and soft bottoms.

Biology: No details available.

Impact: No details available.

General invasion potential and in New Zealand: No details available.

Portunus (Portunus) pelagicus

Portunus (Portunus) pelagicus (Linnaeus, 1758) **Blue crab**

Distribution: <u>native</u>: Indo Pacific; <u>non-native</u>: Mediterranean Sea. In the Mediterranean Sea it was first recorded from Egypt in 1898 (Fox 1924), and then from Palestine (Fox 1924), Turkey (Gruvel 1928), Lebanon (Steinitz 1929), Syria, Cyprus, and Italy. (as cited in CIESM). Established in Mediterranean Sea.

Habitat: intertidal to 55 m; sandy or muddy substrate.

Biology: benthic omnivore.

Impact: fished commercially at times in Mediterranean,

General invasion potential and in New Zealand:

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Scylla serrata

Scylla serrata (Forskål, 1775) **Mangrove crab**

Distribution: <u>native</u>: Indo Pacific (Red Sea to Tahiti); From South Africa to Tahiti, north to Japan, and south to Port Hacking, Australia and the Bay of Islands, New Zealand; including China, Philippines, Indonesia East.

<u>non-native</u>: Hawaii, South West Atlantic (Brazil). In Hawaii it can be found around all of the islands (Coles *et al.* 1999, DeFelice *et al.* 2001).

Invasion history: *Scylla serrata* has been introduced intentionally in Hawaii and throughout the Indo-Pacific to start commercial crab fisheries. In Hawaii, *Scylla serrata* was first introduced into Kaneohe Bay in 1926 to start a commercial crab fishery. A total of 98 crabs were released on Oahu, Hawaii, and Molokai between 1926 and 1935 (Brock 1960). A paper by Edmondson and Wilson written in 1940 reported that the mangrove crab was already an established species. A study done in 1981 in Kahana Estuary, Oahu, Hawaii found that *Scylla serrata* was the most abundant species of crab even though they were highly fished (Maciolek & Timbol 1981).

Habitat: muddy bottoms in brackish water among mangroves and in estuaries (Edmondson 1954, DeFelice *et al.* 2001).

Biology: Large, aggressive omnivorous crab that matures at a carapace width of about 9-11 cm. The male and female begin the mating process when a female is in pre-molting condition. The crabs remain paired for 3 to 4 days until the female molts, and then they copulate (Knuckey 1996). The female then migrates offshore with the fertilized eggs, where they hatch in a couple of weeks (Hill 1996).

Impact: In Hawaii *Scylla serrata* is the largest and most aggressive swimming crab occurring commonly around all of the Hawaiian Islands. *Scylla serrata* is not considered invasive in Hawaii because it has been introduced there intentionally for fisheries and that the fishing pressures would not allow it to become invasive. It has been suggested that it would likely become invasive if not commercially fished (DeFelice *et al.* 2001). *Scylla serrata* is an important source of income for many people. The ecological impacts of this crab have not been studied in Hawaii.

General invasion potential and in New Zealand: Currently New Zealand is probably too cold for this species, but with global warming it could become a threat.

Management: In Hawaii, the population density of *Scylla serrata* seems to stay under control because of the commercial fishing pressure on this species.

Other references: http://www.earlham.edu/~biol/hawaii/marineorganisms.htm#intro (for Hawaiian introductions).

Thalamita gloriensis

Thalamita gloriensis Crosnier, 1962

Distribution: <u>native</u>: Indo West Pacific; <u>non-native</u>: Mediterranean Sea. Recorded from Italy and Sardinia in 1977 (Relini *et al.*1979 as cited in CIESM), but currently regarded as not established (Zenetos *et al.* 2005).

Habitat: coral sands and seaweeds.

Biology: No details available.

Impact: No details available.

General invasion potential and in New Zealand: No details available.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Thalamita indistincta

Thalamita indistincta Apel & Spiridonov, 1998
Distribution: <u>native</u>: Indo Pacific; <u>non-native</u>: Mediterranean Sea (Hasan & Noel 2008)
Habitat: intertidal to 76 m; sandy to muddy bottom.
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Thalamita poissonii

Thalamita poissonii (Audouin, 1826)
Distribution: <u>native</u>: Indo West Pacific (Red Sea to Taiwan); <u>non-native</u>: Mediterranean Sea
Habitat: 0-80 m; under stones, sandy and sandy-mud bottoms, with *Posidonia*, *Caulerpa.*
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

PSEUDOZIOIDEA

PILUMNOIDIDAE

Pilumnoides inglei

Pilumnoides inglei Guinot & Macpherson, 1987 (Synonyms *Pilumnus perlatus*)
Distribution: <u>native</u>: ; <u>non-native</u>: North Sea (status unclear)
Habitat: No details available.
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available.

XANTHOIDEA

PANOPEIDAE (panopeid stone crabs)

Dyspanopeus sayi

Dyspanopeus sayi (Smith, 1869)
Distribution: <u>native</u>: North West Atlantic; <u>non-native</u>: Mediterranean Sea. First recorded from Italy in 1992 (Froglia & Speranza 1993 as cited in CIESM). Established. Very abundant in the lagoon of Venice.
Habitat: shallow brackish waters, soft bottoms with sparse stones and mussel beds.
Biology: No details available.
Impact: may locally outnumber the native *Carcinus aestuarii* and *Pilumnus* spp. (CIESM).
General invasion potential and in New Zealand: No details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Rhithropanopeus harrisii

Rhithropanopeus harrisii (Gould, 1841) **Dwarf crab or Harris mud crab**

European occurrences of *Rhithropanopeus harrisii* were mistakenly named; referred to for many years as *Pilumnus tridentatus* by Maitland in 1874. Buitendijk & Holthuis made the conclusion that the crab was in fact *Rhithropanopeus harrisii* in 1949 (Wolff 2005).

Distribution: <u>native</u>: North West Atlantic (from Gulf of St. Lawrence, Canada to Vera Cruz, Mexico; <u>non-native</u>: Black Sea, Mediterranean, North Sea, North East Pacific, North East Atlantic; Invasion history: first in Netherlands (< 1874), later in the North-East Pacific (Lake Merritt, Oakland and San Francisco Bay, 1937; Coos Bay, Oregon, 1950; Netarts Bay, 1976; Yaquina Bay and Umpqua River, 1978), Panama canal (1969), and at various locations throughout Europe (Baltic coast of Poland, 1951; Copenhagen, 1953; Azov, Black and Caspian Seas, 1958; southern Spain 1980s. Although found in many locations, it is not established in some, such as the Danish Waters: (Jensen & Knudsen 2005). *Rhithropanopeus harisii* is one of those species to have become established after not being detected for years after initial records were taken. It was rediscovered 40 years after initial findings with an established reproductive population (Roche & Torchin 2007). Likely vectors include ballast water, hull fouling and accidental introduction with oyster and seed clams (Roche & Torchin 2007, Rodriguez & Suarez 2001).

Habitat: *Rhithropanopeus harisii* occurs in estuarine habitats (brackish water) and lakes. It is typically found in shallow waters with muddy or sandy substrates, and hiding in shelter such as oyster reefs, vegetation, or debris.

Biology: *Rhithropanopeus harrisii* is known to feed on bivalve molluscs, oligochaetes, and dead fish. Mating is independent of female moulting and usually occurs during the summer months. Typically, females lay between 1200 and 4800 eggs per clutch depending on its size, but can lay up to 16,000 eggs (Turoboyski 1973). Ovigerous females tend to hide among debris, shells, or sediment. *Rhithropanopeus harrisii* has four zoeal larval forms and the megalopa post larval stage. Larval development is fast and takes about sixteen days and sexual maturity is occurs within 9-12 months at the size of about 8 mm (Turoboyski 1973, Forward & Lohman 1983, Cripe *et al.* 2003).

Impact: *Rhithropanopeus harrisii* it is known to compete with native species, foul water, and spread the white spot baculovirus. It is an especially aggressive predator and is known to compete with and displace native crabs, crayfish, and benthophagous fishes, as well as, alter food webs. In Texas they are known to foul PVC intakes in lakeside homes (Roche & Torchin 2007, Grabowski 2005). The deadly white spot baculovirus also causes disease in penaeid shrimp and blue crab. Hayes & Sliwa (2003) list *R. harrisii* as a potential next pest species and possible impacts could include loss of aquaculture/commercial/recreational harvest as it may feed on newly settled mussels and oysters (spat). In its native range, *Rhithropanopeus harrisii* is host to the parasitic barnacle *Loxothylacus panopaei*, which causes growth reduction and castration of its host (Alvarez *et al.* 1995).

General invasion potential and in New Zealand:

Management: As ballast water is assumed to be the main vector, the reduction and prevention of contaminated ballast water is the best preventative method. The chemical Diflunezuron, an active chemical in pesticide Dimilin, has been tried out on hatching larvae of *R. harisii* and found to be lethal in concentrations of 7-10ppb because it inhibits chitin synthesis. However, Diflunezuron is not species specific and therefore eliminates a range of arthropods in the aquatic environment (McEnnulty *et al.* 2001). It is also hard to maintain high concentrations in an open environment (McEnnulty *et al.* 2001).

Other references: USGS Non-indigenous Aquatic Species Database; ISSG database.

XANTHIDAE (xanthid stone crabs)

Atergatis roseus

Atergatis roseus (Rüppel, 1830)
Distribution: <u>native</u>: Indo Pacific (Red Sea to Fiji); <u>non-native</u>: Mediterranean Sea. First recorded from Israel in 1961 (Lewinsohn & Holthuis 1964), then in Lebanon (Shiber 1981) and Turkey (Enzenroß & Enzenroß 1990). (as cited in CIESM). Established and common.
Habitat: 0-12 m; rock and rubble.
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

Subsection Thoracotremata
GRAPSOIDEA

GRAPSIDAE (rock crabs)

Grapsus granulosus

Grapsus granulosus H. Milne Edwards, 1853
Distribution: <u>native</u>: Red Sea; <u>non-native</u>: Mediterranean Sea.
Habitat: rocky intertidal.
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

PLAGUSIIDAE

Percnon gibbesi

Percnon gibbesi (H. Milne Edwards, 1853)
Distribution: <u>native</u>: N & S E At (California to Chile), N & S W At (Florida to Brazil), Madeira to Gulf of Guinea (N & S E At); <u>non-native</u>: Mediterranean Sea. First recorded from Italy in 1999 (Relini *et al.* 2000 as cited in CIESM), then rapidly from other locations in the Mediterranean. Established and locally common.
Habitat: shallow subtidal, mostly 1-2 m depth; between rocks and boulders (Thessalou-Legaki *et al.* 2006, Yokes & Galil 2006).
Biology: Feeds primarily on algae (Puccio *et al.* 2006).
Impact: No details available.
General invasion potential and in New Zealand: No details available.

Plagusia squamosa

Plagusia squamosa (Herbst, 1790) **synonym** *Plagusia tuberculata*
Distribution: <u>native</u>: IP (Red Sea to eastern Pacific); <u>non-native</u>: Mediterranean Sea. Single record from Lebanon (Shiber 1981 as cited in CIESM).

Habitat: intertidal**;** among stones, corals, known to attach itself to floating timber and the hull of ships
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available.
Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

SESARMIDAE

Nanosesarma minutum

Nanosesarma minutum De Man, 1887
Distribution: <u>native</u>: I W P (E Africa to Thailand); <u>non-native</u>: NW P (Hawaii)
Habitat: intertidal and subtidal; estuarine, associated with oyster bed.
Biology: No details available.
Impact: No details available.
General invasion potential and in New Zealand: No details available.

VARUNIDAE

Eriocheir sinensis

Eriocheir sinensis H. Milne Edwards, 1853 **Chinese mitten crab**
Distribution: native: North-West Pacific (China and North Korean Peninsula); non-native distribution: since 1912 in North-East Atlantic (first in Germany, now from Finland to Sweden, Russia, Poland, Germany, Czech Republic, Netherlands, Belgium, England, France, Sapin, Portugal), B, Bl, No, M (via the Garonne canal system); since 1992 in North-West Atlantic (San Francisco Bay); found 1965 in Detroit River and later some records from Great Lakes, but not established there; 2004 first records in St. Lawrence River (Veilleux & de Lafontaine 2007); isolated records from Hawaii but not established. Currently, it is not established in Danish Waters (Jensen & Knudsen 2005). Several vectors have been identified for *Eriocheir sinensis* and include the illegal introduction for the live food trade, ballast water and ship hull fouling (Cohen & Carlton 1997). In addition, natural dispersal is likely after initial invasion. It has been suggested that *E. sinensis* has the potential to establish itself in all major UK estuaries after comparing the current invasion behaviour in the United Kingdom with historic invasion in northern Europe (Herborg *et al.* 2005). The potential distribution in North America in major ports was estimated based on a model using environmental match and volume of ballast water received. Chesapeake Bay and Portland were highlighted as locations of high invasion risk and several other locations are likely to be invaded too (Herborg *et al.* 2005).
Habitat: *Eriocheir sinensis* is catadromous and spends most of its life in rivers, but must migrate to the sea to breed. It therefore occupies estuarine habitats, lakes, riparian zones, water courses and wetlands. It can also travel over dry land.
Biology: *Eriocheir sinensis* is catadromous (migrates between freshwater, estuarine and marine environments), tolerates a wide range of abiotic conditions (salinities and temperatures) and is found in temperate climates around the world. *Eriocheir sinensis* is an omnivore with juveniles primarily eating vegetation and adult crabs mainly small invertebrates such as worms and clams. Overall, it has an opportunistic diet including

algae, detritus, and a variety of macro-invertebrates (Panning 1938; Hoestlandt 1948; Gollasch 1999; Rudnick *et al.* 2003). The time to maturity in the wild varies between 2-5 years and appears to depend on environmental factors (Herborg *et al.* 2005, Rudnick *et al.* 2005). Crabs reproduce only once during their lifetime. They migrate to brackish waters of estuaries or the sea to mate where females typically lay between 250,000 to 1 million eggs. Males die after the mating season and females after releasing the larvae. In the spring the eggs hatch into larvae and after about six to seven weeks these metamorphose into juvenile crabs, which then migrate back up the river into freshwater to complete the life cycle. Juvenile crabs form dense colonies and create burrows in the intertidal portions of streams.

Impact: *Eriocheir sinensis* has many major impacts which can include competing for resources with native freshwater invertebrates (Clark *et al.* 1998), modifying habitats and causing erosion through its intensive burrowing activity (Dutton & Conroy 1998 in Herborg *et al.* 2005), feeding on bait and trapped fish which cost fisheries and aquaculture industries (Ingle & Andrews 1976), and blocking water intakes in irrigation and water supply schemes (Siegfried 1999). In addition, *Eriocheir sinensis* can carry a lung fluke that infects humans (Cohen 2003). In Britain vulnerable freshwater species may be eaten and out-competed (Owen 2003). Under laboratory conditions, native *Carcinus maenas* were excluded from shelters by *E. sinensis* (Gilbey *et al.* 2008). Stream banks in Europe and the USA are being eroded by the burrowing behaviour of the dense juvenile colonies (Peters & Panning 1933; Dutton & Conroy 1998; Rudnick *et al.* 2003). *Eriocheir sinensis* steals bait and damages fishing gear which hinders commercial and recreational fishing (Panning 1938; Rudnick & Resh 2002) and may feed on trapped fish in commercial aquaculture ponds. The mitten crab is the secondary intermediate host for the Oriental lung fluke, with mammals, including humans, being the final host. Humans can become infested by eating raw or poorly cooked mitten crabs. However, neither this human parasite nor its primary snail host have been found in California (EATM 1999). The Chinese mitten crab is a culinary delicacy in Asia and supports a $1.25 billion per annum aquaculture industry in China (Herborg *et al.* 2005). Crabs have been used as bait for eel fishing, to produce fish meal, cosmetic products and as fertilizer in agriculture.

General invasion potential and in New Zealand:

Management: Control of this species is difficult because of its abundance, ubiquity, high reproductive rate, and wide range of physiological tolerances (Deborah *et al.* 2003). Intense trapping of crabs has not been sufficient to reduce the damage caused by crabs significantly. Electrical screens were installed in the 1930-40's to prevent the migration of the crab up rivers in Germany but with little success (McEnnulty *et al.* 2001). Alternatively, it has been suggested to commercially harvest them in Britain and to export them to China (Owen 2003).

Key references: Veilleux & de Lafontaine 2007; ISSG (Gollasch 2006)

Hemigrapsus penicillatus

Hemigrapsus penicillatus (De Haan, 1835)

Another Asian species, *Hemigrapsus takanoi* has only been recently described by Asakura & Watanabe (2005) and separated from the species *Hemigrapsus penicillatus*. Consequently, several previous records of *H. penicillatus* in Europe were actually records of *H. takanoi*. There is still some uncertainty from the literature, which species is actually in which country.

Distribution: native: Northern Japan to China; non-native distribution: in North Sea
Habitat:
Biology:

Impact: Hayes & Sliwa (2003) report *H. penicillatus* known to dominate and outcompete and limit the resources of native spp. and to be a predator of native spp., but this might now actually refer to *H. takanoi*.

General invasion potential and in New Zealand: In Australia *Hemigrapsus penicillatus* has been listed as a potential next pest species (Hayes & Sliwa 2003), however, this might actually now refer to *H. takanoi* instead.

Hemigrapsus sanguineus

Hemigrapsus sanguineus (De Haan, 1853) **Japanese or Asian shore crab**

Distribution: <u>native</u>: North-West Pacific (from Sakhalin to Hong Kong and Japan); <u>non-native</u> distribution: North-West Atlantic, Mediterranean Sea; history: In America, it was first reported in 1988 in New Jersey and has subsequently spread north to Massachusetts and south to North Carolina (McDermott 1998). In Europe, it has been first found in 1999 in the Netherlands and France (Breton *et al.* 2002) and in 2002 in the Mediterranean (Schubart 2003).

Habitat: *Hemigrapsus sanguineus* occupies estuarine and marine habitats and occurs there predominantly in the middle and lower intertidal and occasionally in the sub-tidal and preferring structurally complex habitats with a lot of shelter (Lohrer *et al.* 2000). In Japan, *H. sanguineus* is commonly found among boulders on rocky intertidal shores (Fukui 1988). It prefers rocky hard-bottom habitats or other hard structures such as mussel beds or oyster reefs where it can shelter easily. It can also be found on tidal flats hiding under rocks or shells. The distribution and population density often increases with the availability of shelter (Lohrer *et al.* 2000). In the North-West Atlantic it occupies the same habitat as several mud crabs (Xanthidae) and juvenile green crabs *Carcinus maenas* (Kopin *et al.* 2001, McDermott 1998) and in the North-East Atlantic in the same habitat as the two other exotic crabs, *Carcinus maenas* and *Hemigrapsus takanoi* (formerly presumed to be *H. penicillatus*)(Breton *et al.* 2002).

Biology and natural history: *Hemigrapsus sanguineus* can tolerate a wide range of salinities and temperature, as well as damp conditions in the upper intertidal regions (Benson, 2005). *Hemigrapsus sanguineus* is an opportunistic omnivore and will feed on a range of marine invertebrates including crustaceans, commercially important bivalves such as the blue mussels *Mytilus edulis*, soft-shell clams *Mya arenaria*, and oysters *Crassostrea virginica*, and algae (McDermott 1998, Brousseau *et al.* 2001). When given the choice *Hemigrapsus sanguineus* showed a strong preference of animal food over algae (Brousseau & Baglivo 2005). *Hemigrapsus sanguineus* can be an important predator of juvenile blue mussels *Mytilus edulis*, especially when it occurs in high population densities and compared to the other predator Carcinus maenas (Lohrer & Whitlach 2002). *Hemigrapsus sanguineus* is a carrier of the White Spotted S Virus (WSSV) (Maeda *et al.* 1998). Larval development takes about one month (depending on temperature) and this long development has the potential for long distant transport depending on the local currents (Epifanio *et al.* 1998). Settlement of megalopa larvae and metamorphosis to the juvenile stage appears to be highly species specific and induced by exposure to water-soluble exudates produced by conspecific adults (Kopin *et al.* 2001, Steinberg *et al.* 2007, but see O'Connor 2007). *H. sanguineus* has a high reproductive output with a relatively long breeding season over several months (5 in New Jersey) and includes two or more broods annually with up to 44,000 eggs (McDermott 1998b). In addition growth and maturation are rapid and crabs are mature within a few months. McDermott (1998a) suggested that the length of the reproductive period of *H. sanguineus* is related to latitude and therefore water temperature as in the warm southern Japan the breeding season is 8 months long whereas in colder northern Japan it lasts 3 months. A total of 13 ecto-symbionts have been identified from *H.*

sanguineus along the US Atlantic coast, but no gill or internal parasites have been found (McDermott 2007).

Impact: *H. sanguineus* has the potential to cause significant changes in the inshore marine and estuarine communities of southern New England and mid-Atlantic coast because of its predation and possible habitat displacement of several important native species (Gerard *et al.* 1999). *Hemigrapsus sanguineus* has been observed to occupy in parts, the same habitat as the two other non-indigenous crabs *Hemigrapsus penicillatus* and *Carcinus maenas* in France (Breton *et al.* 2002) and other regions (Lohrer & Whitlach 2002). *Hemigrapsus sanguineus* has now replaced *Carcinus maenas* in some location from their intertidal habitat and has also been shown to be a strong competitor for food and space in the laboratory (Brousseau *et al.* 2000). In addition, it competes for habitat and possibly displaces several native crabs, such as xanthid and mud crabs, of the mid-Atlantic coast of North America (McDermott 1991; Gerard *et al.* 1999). In comparative feeding and behaviour trials involving 3 crab species, the native blue crab *Callinectes sapidus* and the two exotic *Hemigrapsus sanguineus* and *Carcinus maenas*, it was shown that *H. sanguineus* is evenly successful when it comes to competing for food with juvenile *C. sapidus* but less so compared to *Carcinus maenas* (MacDonald *et al.* 2007). Furthermore, it has been shown that *H. sanguineus* can, similar to *Carcinus maenas*, induce shell thickening in mussels as a predator defence mechanism. Freeman and Byers (2006) showed that in southern New England (where the crab occurs) mussels express inducible shell thickening when exposed to waterborne cues from *Hemigrapsus*, whereas naïve northern mussel populations (where the crab does not occur yet) do not show any changes.

General invasion potential and in New Zealand: In Australia *Hemigrapsus sanguineus* has been identified as a potential next pest species because it fitted four selection criteria for potential pest ("A. a species has been reported in a shipping vector or has a ship-mediated invasion history; B. the vector still exists; C. the species is responsible for economic or environmental harm; and D. it is exotic to Australia or present in Australia but subject to official control") (Hayes & Sliwa 2003). In addition, Hayes & Sliwa (2003) listed loss of aquaculture/commercial/recreational harvest, dominates/out competes/limits the resources of native spp, predation on native spp., and introduces/facilitates new pathogens or parasites, as known impacts for *Hemigrapsus sanguineus*.

Management: Ballast water management will help to reduce new introductions from occurring. No parasites have been found in *H. sanguineus* in its introduced range along the US Atlantic coast that might control the population (McDermott 2007).

Other references: ISSG database

Hemigrapsus takanoi

Hemigrapsus takanoi Asakura & Watanabe, 2005

Hemigrapsus takanoi has only been recently described by Asakura & Watanabe (2005) and separated from the species *Hemigrapsus penicillatus*. Consequently, several previous records of *H. penicillatus* in Europe were actually records of *H. takanoi*. There is still some uncertainty from the literature, which species is actually in which country. It is also a bit similar looking to another invasive species, *Hemigrapsus sanguineus*.

Distribution: <u>native</u>: North-West Pacific (Japan to China, Taiwan); <u>non-native distribution</u>: North –East Atlantic, North Sea. History: It was first documented in 1993 from France and is now present in several other European countries (Spain, Netherlands, Belgium, Germany) (Noël *et al.* 1997 and references therein).

Habitat: In Japan, *H. takanoi* can be commonly found in bays and estuaries and includes areas where salinities and temperatures fluctuate highly (7-35 o/oo S and 12.5-20 C,

respectively (Mingkid *et al.* 2006). In France, *H. takanoi* it was mostly found in sheltered areas of the mid-littoral zone and was locally abundant with up to 10-20 individuals per m^2 (Noël *et al.* 1997).

Biology: The salinity tolerance of larvae of *Hemigrapsus takanoi* from hatching to the first juvenile stage was investigated by Mingkid *et al.* (2006) in the laboratory at an average water temperature of about 24 C. Successful development occurred only at higher salinities (at 25, 30 and 35 o/oo S), no larvae developed further then the megalopa stage in lower salinities (10, 15 and 20 o/oo S), and only few larvae metamorphosed to the second zoeal stage at very low salinity (5 o/oo S) and died shortly after. This shows that although juveniles and adults can be found in a range of salinities, higher salinities are required for successful larval development (Mingkid *et al.* 2006).

Impact: This species is likely to compete for food and shelter with native shore crabs on the rocky shore habitat in particular where it occurs in high densities (Noel *et al.* 1997; Gollasch 1999). This might also include competition with *Carcinus maenas* in Europe.

General invasion potential and for New Zealand: It has been suggested that because this species has a broad temperature tolerance (cold to tropical native habitats) that it is likely to colonize most of the European and North-African coasts (Noël *et al.* 1997). In the North-West Atlantic, this species has also been identified as a potential next invader and ID cards are for example available in the Gulf of Maine from Massachusetts office of Coastal Zone Management, to increase public awareness (http://www.mass.gov/czm/invasives/). In New Zealand, this species is also likely to find a range of suitable habitats and temperature and salinity conditions especially in the North Island. There is might compete with the local native shore crabs, in particular *Hemigrapsus crenulatus*, for food and shelter.

OCYPODOIDEA

MACROPHTHALMIDAE (ocypodid crabs)

Macrophthalmus graeffei

Macrophthalmus graeffei A. Milne Edwards, 1873

Distribution: native: West Indo Pacific; non-native: Mediterranean Sea. First recorded from Turkey in 1994 (Enzenroß & Enzenroß 1995) and then in Israel in2003 (Ksiunin & Galil 2004) (as cited in CIESM).

Habitat: 5-74 m; fine sand with little mud.

Biology: No details available.

Impact: No details available.

General invasion potential and in New Zealand: No details available. Unlikely to invade New Zealand as Suez Canal was vector.

Key reference: CIESM 2008 Atlas of exotic crustaceans in the Mediterranean.

4.5 DISCUSSION

The success of a marine invader is a product of many factors, such as surviving transport, becoming established in the new location by surviving and reproducing under the new abiotic and biotic conditions and spreading from there (e.g. Carlton 1996, Ruiz *et al.* 2000). In addition, high propagule supply (density, frequency, duration) will allow easier establishment (e.g., Carlton & Geller 1993, Kolar & Lodge 2001, Colautti *et al.* 2006). Furthermore, the

exact impact of the invasive species is even harder to predict (Strauss *et al.* 2006, Strayer *et al.* 2006, White *et al.* 2006).

However, overall the zoobenthos has been shown to be the dominant alien group in the European "Seas" (which includes the Mediterranean, Atlantic, North Sea, Baltic Sea, Black Sea and Arctic) accounting for 57% of non-indigenous species (Streftaris *et al.* 2005). In the European Seas molluscs are often the prevailing phylum of alien zoobenthos accounting for about 23 % of all NIS followed by brachyuran decapods and others (Streftaris *et al.* 2005). In comparison, in San Francisco Bay crustaceans are the richest introduced taxon (53 species), followed by molluscs (30) and fish (28) (Cohen & Carlton 1995). In Pearl Harbour, molluscs (38) and crustaceans (35) comprise the two richest introduced groups (Coles *et al.* 1999). In Port Philips Bay (Australia) crustaceans were the fourth richest invasive taxon (after bryozoans, cnidarians, and chordates) and molluscs ranked seventh (Hewitt *et al.* 2004).

Dominant/prominent non-indigenous brachyuran families

Three brachyuran super-families stand out in their high number of recorded non-indigenous species: namely the Portunoidea (swimming crabs), Grapsoidea (shore crabs) and Majioidea (spider crabs), fifteen, eight and seven, respectively. Xanthoidea are remarkable as all of their five recorded non-indigenous species have also become established.

Interestingly, the Cancroidea include in total six species which have been recorded outside their native range. The New Zealand crab *Metacarcinus novaezelandiae* which was most likely accidentally transferred with oysters to southern Australia and Tasmania, has become established there (Poore 2004). The edible European crab *Cancer pagurus* was deliberately introduced by early settlers between 1907 -1913 for commercial fisheries to New Zealand (Thomson & Anderton 1921). Although an estimated 40 million larvae and 19 adults were released (Thomson 1922) none were ever recorded subsequently.

The Asian cancer crabs *Romaleon gibbosulum* and *Glebocarcinus amphioetus* were recorded in small numbers from New Zealand in 2001 and 2003 during baseline port surveys (Inglis *et al.* 2005, 2006a, b, c, d), but none were subsequently found despite intensive targeted surveys (Brockerhoff pers. obs.). Single specimens of the North-East Pacific crab *Metacarcinus magister* have been reported from Japan (Abe 1981) and Massachusetts (REF), but not subsequently.

Larvae of the north-west Atlantic crab *Cancer irroratus* travelled and survived 17 days in ballast water from New York to England (Hamer *et al.* 1998). The megalopa larvae were transferred to the laboratory and grew to 58 mm CW in 5 months. It was estimated that there were up to 32,000 individuals onboard (Hamer *et al.* 1998). Overall, the water temperature and salinity range of the southern North Sea would probably allow this species to survive there (Hamer *et al.* 1998), but none have yet been reported outside their native range.

The families Portunidae (swimming crabs), Varunidae ('grapsid crabs') and Leucosiidae (pebble crabs) are the families with the highest number of established non-indigenous species.

Life history trends of non-indigenous brachyuran crabs

There are several life history traits that appear to facilitate marine invasions in brachyuran crabs. Brachyuran crabs that have become established are mostly intertidal to shallow subtidal species and are capable of tolerating a wider range of temperatures and salinities. They tend to be omnivores or generalist predators and are often highly aggressive and competitive in regards to food and shelter. They are often widespread and common in their native range. Their reproductive output is typically high which can be achieved by, for example, maturing early (within a couple of years), producing several thousands eggs per clutch or several clutches per year. Long larval development (i.e. several weeks before settling) can facilitate distribution from original invasion area. Migratory behaviour allows the use of a range of habitats and depths and breeding offshore can increase successful reproduction by avoiding hypoxia/organic pollution of shallow bays, ports or harbours.

Some of these are similar traits pointed out by Hutchings *et al.* (2002) for species with high invasion potential. Examples of brachyuran crabs that follow this pattern particularly well are *Carcinus maenas* (Klassen & Locke 2007), *Charybdis hellerii* (Dineen *et al.* 2001) and *Eriocheir sinensis* (Veilleux & De Lafontaine 2007). Although limited information is available on the two Asian crabs *Romaleon gibbosulum* and *Glebocarcinus amphioetus* it is likely that their life history also fit this general trend.

Interestingly, it has been observed that invasions can cause an increase in size in some marine and estuarine invertebrates in the new location (phenotypic change). Grosholz and Ruiz (2003) found that 12 out of 19 species were significantly larger in the introduced range compared with the native range. They also noted that this invasion-driven increase in body size contrasts with the pattern observed in many other taxa including plants, mammals and lizards. Brachyuran species showing this trend of larger size are *Rhithropanopeus harrisii*, *Eriocheir sinensis* and *Carcinus maenas*, but not *Hemigrapsus sanguineus*. Possible explanations for increased size could be the greater resources in the introduced range relative to the native range which could translate into faster growth and larger body size and the absence of predators or parasites in the introduced range (Grosholz & Ruiz 2003). Findings from modern invasions support the idea that size increase may often follow range expansions of marine invertebrates and can result from rapid phenotypic change during the early stages of colonization.

Invasion dynamics of non-indigenous brachyurans

Grosholz (1996) reviewed the spread rate of ten non-indigenous species. Large year-to-year variation in the geographic expansion rate of the ten marine non-indigenous species were found, which were possibly due to the variation in the ocean surface currents (Grosholz 1996). In this study, no link between the mean annual rate of range expansion and planktonic duration was found. In addition, it appeared that the spread rate in one location was not a good indicator of spread for other locations in the case of *Carcinus maenas* (Grosholz 1996). Similarly, it was suggested for *Carcinus maenas* in Australia that chiefly localised recruitment occurs despite long planktonic durations and off-shore development of larvae and only occasionally punctuated wide scale dispersal (Thresher *et al.* 2003). In addition, global distribution patterns of exotic *Carcinus maenas* and *C. aestuarii* seem to be primarily regulated by temperature. They have become established in Atlantic North America, Australia, South Africa, Japan and Pacific North America, but not in the tropical regions were one-off collections were made (e.g. Hawaiian Islands, Sri Lanka, Madagascar) (Carlton & Cohen 2003).

Regional observations

The ability of a species to invade a new area will depend on the biophysical similarity compared to its native range, the genetic fitness, health and stress status of the local community, as well as the biological competition for food and shelter it will encounter (Hutchings *et al.* 2002).

The Mediterranean Sea has 42 of the 57 exotic brachyuran species recorded worldwide of which about half have become established. This high number of exotic brachyurans has its origin partly to the migrations through the Suez Canal into the Mediterranean (Lessepsian or Erythrean migration) but also includes other shipping, aquaculture and unknown introductions (Streftaris *et al.* 2005). There is no other region in the world that has so many non-indigenous brachyuran crabs.

In New Zealand four brachyuran species have been recorded and two became established (*Pyromaia tuberculata, Charybdis (Charybdis) japonica*). New Zealand has a relatively low brachyuran diversity of less than a hundred species (McLay 1988). Generally, it has been thought that communities high in species diversity tend to be more successful in resisting invaders than those low in species diversity (e.g. Elton 1958, MacArthur 1972, Case 1990), although several studies have found a positive relationship between species diversity and the number of introduced species (Levine & D'Antonio 1999, see also review by Fridley *et al.* 2007). Non-indigenous brachyurans, if they can tolerate the physical conditions in New Zealand waters, might therefore experience limited biological competition from native brachyurans.

In Australia three brachyuran species have been recorded and have also become established (*Pyromaia tuberculata, Metacarcinus novaezelandiae, Carcinus maenas*). In Australia, the dominant mode of introduction of any marine NIS has been hull fouling, followed by accidental releases associated with mariculture and ballast water at about equal level, and then dry ballast and intentional releases (Thresher *et al.* 1999, Hewitt 2003).

It has been observed that there are currently fewer marine introductions in tropical regions compared to temperate (Hutchings *et al.* 2002). For Australia, possible reasons for this could be the high physical stresses in the subequatorial latitudes of northern Australia, which can include strong seasonal temperature and salinity changes. In addition, non-indigenous species will encounter high levels of biological competition because of the high biodiversity in tropical communities (Hutchings *et al.* 2002).

Potential next pests and targeted surveys in the South Pacific

In New Zealand and Australia, long term programmes have been started that will provide baseline information to assist in the development of national control plans. For example, baseline and targeted surveys for non-indigenous marine species in ports and other coastal locations have been carried out (e.g. Inglis *et al.* 2005, 2006, Hewitt *et al.* 1999) and potential next pest species have been identified and ranked for possible future management (New Zealand Biosecurity website (http://www.biosecurity.govt.nz/), Hayes & Sliwa 2005).

In New Zealand two brachyuran species are currently included in the targeted marine surveys: *Carcinus maenas* and *Eriocheir sinensis* (Biosecurity New Zealand website

(http://www.biosecurity.govt.nz/). In Australia four brachyurans have been selected as potential next marine pest species: *Callinectes sapidus*, *Charybdis japonica*, *Eriocheir sinensis* and *Hemigrapsus sanguineus* (Hayes & Sliwa 2005). The ranking was done using a list of 22 vectors and 15 impact categories (Hayes & Sliwa 2005). *Hemigrapsus penicillatus* (species identity currently uncertain, could be *H. tak*anoi instead) and *Rhithropanopeus harisii* used to be on the next pest list (Hayes & Sliwa 2003), but were removed because of uncertainty of their exact impact in the invaded area.

Developing lists for potential next pest species using information on invasiveness from other countries allows targeting particular species in surveys and channelling the limited resources available for such work. However, it seems important to include also those species into watch lists that were previously found in a country. For example, two cancrid crabs found in five ports in New Zealand in 2001 and 2003 were recorded in small numbers and do not appear to be currently established. However, they are probably likely to arrive in New Zealand again and early detection might allow strong measures to prevent establishment in the future.

Pest management options for non-indigenous brachyuran crabs

In general, the options for managing invasive marine species range from the more classical methods of physical removal or use of chemicals (biocides) to biocontrol, genetic technology, environmental remediation, commercial exploitation and intensification of native species (such as predators, herbivores, parasites or diseases) and others (Thresher & Kuris 2004). It appears that the acceptability of the control methods vary largely and depend on their perceived cultural and political acceptability and likely effectiveness (Thresher & Kuris 2004) and side effects. Physical removal and biocides were seen as potential good control methods for small scale incursions whereas currently no good acceptable control methods seemed available for large-scale incursions (Thresher & Kuris 2004). It has been therefore suggested that one could develop new techniques, increase the effectiveness of acceptable techniques, or increase the acceptability of potential effective techniques (Thresher & Kuris 2004). Biological control in the marine environment has been viewed as too risky by some scientists (Secord 2003).

We are not aware of any attempted eradication programmes for brachyuran crabs. It seems that either only few specimens are recorded which then do not become established and do not require control measures or new non-indigenous species are already too numerous and widespread to consider eradication measures.

However, in the past various methods have been tried to reduce the population size of non-indigenous brachyurans in their new range and some new potential control methods are being pursued. For example, physical removal setting nets and trapping has been tried for *Eriocheir sinensis* in Germany, but with no substantial or long-term effect. Similarly, fencing, trapping and poisoning have been tried for *Carcinus maenas* with limited success (see details in Klassen & Locke 2007). The parasitic barnacle *Sacculina carcini* has been investigated in the laboratory as a potential biological control agent for *Carcinus maenas*, but was found to be not host-specific enough because it also infected, and often killed, native species in Australia (Thresher *et al.* 2000; Goddard *et al.* 2005). In general, parasites used in biological control have the potential to reduce host densities but do not eradicate pests.

In summary, non-indigenous brachyuran crabs are a significant issue in many parts of the world (unless they are commercially fished) as they often establish high population densities and compete fiercely with local fauna for food and shelter. Although the total number of non-

indigenous brachyuran crabs is smaller compared to other major taxa (e.g., Mollusca) their impact can be substantial. Consequently, preventative measures are important as well as developing better control techniques to limit their impacts. Biosecurity is preferable to having to try and eradicate species after they arrive.

Conclusions and recommendations

Although two species of cancrid crabs were detected in New Zealand waters, neither has become established yet, but monitoring of ports should be maintained in the future so that we can have sufficient warning of their possible establishment.

The major discovery of our research has been the presence of native crab parasites that we didn't know that we had (castrating rhizocephalans and egg predators). These species could be an important part of the biotic resistance of New Zealand marine communities that could help prevent or reduce colonization by aliens. For this reason we recommend that further funds be invested in making a more detailed study of these parasites and possibly extent parasite surveys to other native crabs. Since they are already native to New Zealand it may be possible to target exotic crabs to help inhibit or suppress alien colonization. To do this we need to know more about them.

Acknowledgements

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Appendices

APPENDIX 1.

Details of cancrid crab surveys carried out from Feb. 2005 to Mar. 2007: collection months, methods and number of endemic crab *Metacarcinus novaezelandiae* sampled.

Location	Months surveyed	Baited crab traps set	Pylons scraped	Dredge hauls taken	Crab shelters sampled	*Metacarcinus novaezelandiae (endemic)*
Lyttelton Harbour						
Port	Mar 2005	15				6
	Mar 2005		30			4
	Aug 2005	11				0
	Dec 2005	24				1
	Feb 2006	65				125
	May 2006	24				37
New Marina	Mar 2005	7				7
	Apr 2005	15				68
	Oct 2005		20			15
	Nov 2005		10			8
	Nov 2005				12	5
	Dec 2005		30			12
	Dec 2005				36	5
	Jan 2006		10			3
	Jan 2006				12	1
	Feb 2006		20			4
	Feb 2006				9	0
	Mar 2006		10			5
	Mar 2006				9	7
	May 2006	10				2
	Oct 2006	10				22
Inner Harbour	Feb 2005	7				6
	Mar 2005	7				39
	Jun 2005			14		0
	Oct 2005			10		0
	Jan 2006			14		0
Diamond Harbour	Mar 2005		15			6
	Oct 2005		10			4
	Jan 2006		10			0
	Apr 2006		10			0
Banks Peninsula						
Taylors Mistake	Feb 2005				3	1
	Mar 2005				6	4
	Apr 2005				3	0
	May 2005				5	9
	Jun 2005				6	94
	Jun 2005	18				95
	Jul 2005	8				83
Le Bons Bay	Feb 2005				3	2
	May 2005				3	2
	Aug 2005				3	25

Appendix 1 continued.

Location	Months surveyed	Baited crab traps set	Pylons scraped	Dredge hauls taken	Crab shelters sampled	*Metacarcinus novaezelandiae (endemic)*
Pigeon Bay	Feb 2005				3	0
	Mar 2005				3	1
	Apr 2005				1	2
	May 2005				3	3
	Jun 2005				1	1
	Jun 2005	16				27
	Jul 2005				3	27
	Jul 2005	8				1
Akaroa	Feb 2005	10				2
	Feb 2005				6	0
	Mar 2005				5	1
	Apr 2005				2	0
	May 2005				1	0
	Nov 2006	20				13
Port Levy	Oct 2006	23				100
Pegasus Bay						
Scarborough	Aug 2006	20				234
Timaru						
Port	Mar 2005	15				0
	Mar 2005		30			3
	Sep 2005	21				80
	Feb 2006	36				49
	Feb 2006		20			2
Caroline Bay	Jun 2005	17				197
	Sep 2005	21				1037
Gisborne						
Port	Mar 2006	101				42
	Mar 2006		20			0
Outer 'Port"	Mar 2006	3				0
Bluff						
Port	Apr 2006	103				3
	Apr 2006		20			0
Wellington						
Port	May 2006	43				3
	May 2006		40			0
	Sept 2006	18				5
Seaview Wharf	May 2006	28				56
	Sept 2006	48				207
	Sept 2006			8		0
	Nov 2006	42				154
	Dec 2006	32				91
	Feb 2007	32				120
	Mar 2007	26				55

Appendix 1. continued.

Location	Months surveyed	Baited crab traps set	Pylons scraped	Dredge hauls taken	Crab shelters sampled	*Metacarcinus novaezelandiae (endemic)*
Burnham Wharf	May 2006	28				37
	May 2006		40			0
	Sept 2006	58				232
	Sept 2006			1		0
	Nov 2006	23				56
	Dec 2006	32				41
	Feb 2007	32				46
	Mar 2007	36				48
Greta Point	Sep 2006	7				3
Island Bay, South Shore	Sep 2006	31				1
Evans Bay	Sep 2006			4		2
Shelly Bay	Sep 2006			4		0

APPENDIX 2.

Registration numbers of cancrid crab species *Romaleon gibbosulum* and *Glebocarcinus amphioetus* examined at the Osaka Museum of Natural History, Osaka, Japan.

	Reg. Number	Num. of individuals	Date	Locality
Romaleon gibbosulum				
OMNH-Ar	3024	2	10/05/1985	Off the coast of Ootani (8.9m depth), Tsuna Town, Tsuna District, Hyogo Prefecture, Japan
OMNH-Ar	4459	1	30/06/1996	Chudoh, Aio Town, Yoshiki District, Yamaguchi Prefecture, Japan
OMNH-Ar	4625	1	26/08/2000	Shin-Maiko, Mitsu town, Hyogo Prefecture, Japan
OMNH-Ar	5307	1	02/04/2002	Estuary of Kushida River, Mie Prefecture, Japan
OMNH-Ar	6562	2	27/05/2003	Off the coast of Marugame City, Kagawa Prefecture, Japan
OMNH-Ar	5944	7	10/05/1985	Off the coast of Ootani (3.7m depth, St.6), Tsuna Town, Tsuna District, Hyogo Prefecture, Japan
OMNH-Ar	6096	6	19/04/2001	Off the coast of Sakai City, Osaka Prefecture, Japan
OMNH-Ar	5945	13	09/05/1985	Off the coast of Shio (7.7m depth, St.2-1), Tsuna Town, Tsuna District, Hyogo Prefecture, Japan
OMNH-Ar	5946	7	09/05/1985	Off the coast of Shio (7.7m depth, St.2-2), Tsuna Town, Tsuna District, Hyogo Prefecture, Japan
OMNH-Ar	6016	26	21/03/2000	Hannan 2nd Area, Kishiwada City, Osaka Prefecture, Japan
OMNH	unregistered	1	19/08/1970	Osaka Bay, Hiraiso, Higashi-Tarumi, Tarumi Ward, Kobe City, Japan
OMNH	unregistered	22		Osaka Bay, Off the coast of Awajishima Is., Japan (St.29.34)
Glebocarcinus amphioetus				
OMNH-Ar	3177	1	27/06/1986	Off the coast of Tannowa, Osaka Bay, Japan
OMNH-Ar	3179	1	28/06/1986	Off the coast of Tarui, Osaka Bay, Japan
OMNH	unregistered	2	14/08/1983	Kamishima, Toba City, Mie Prefecture, Japan
OMNH	unregistered	1	26/05/1969	Osaka Bay, Off the coast of Higashi-Tarumi, Tarumi Ward, Kobe City, Japan