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**Investigating the socio-economic impacts of the
introduced Asian paddle crab, *Charybdis japonica*,
on New Zealand's native paddle crab fishery**

A thesis
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of the requirements for the degree
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Abstract

Despite the body of scientific research that exists on *Charybdis japonica* since its discovery in New Zealand in 2000, an investigation into the socio-economic impacts this introduced species may have was lacking. This study focuses on the potential socio-economic impacts from *C. japonica* on NZ's native paddle crab (*Ovalipes catharus*) fishery. *Charybdis japonica* has spread steadily throughout the North Island of NZ, predominantly in an area that coincides with the main commercial fishing area for *O. catharus* (federally managed and defined as 'PAD1'). Fishers perceptions of change and impacts in the fishery were investigated across the commercial and recreational sectors within this focus area. Qualitative, semi-structured interviews with commercial crab fishers covered three main areas: (1) background information on the *O. catharus* fishery, (2) perceptions of change in the fishery, (3) knowledge of *C. japonica* and perceived impact. Surveys with recreational fishers also covered these areas, with additional questions on their perceptions of the value of certain coastal environmental aspects (i.e., safety, cleanliness, biodiversity).

Commercial fisheries catch data for the five main *O. catharus* fishing regions was also analysed to assess if a significant change in catch rates pre- and post- the arrival of *C. japonica* in NZ had occurred. Results showed significant changes in PAD1, PAD7 and PAD8 fisheries management areas. Given *C. japonica* has not yet been found in PAD7 and PAD8, catch rate changes within these three areas are likely due to other unmeasured variables. Commercial fishers predominantly suggested *C. japonica* had not yet had an observable impact on the *O. catharus* fishery. Recreational fishers that participated in this study had only had a short-term exposure to the fishery (the majority had started fishing for crabs less than a year ago), thus they had limited perceptions of change within the fishery. Commercial and recreational fishers were also tested on their ability to accurately identify the two crab species. Both sectors accurately identified *O. catharus* 95% of the time and *C. japonica* 55% of the time from a series of four images, with no statistically significant difference in accuracy between the two sectors.

Despite some evidence of self-reported awareness of *C. japonica* in this study, further sustained public education to enable identification of this introduced species is needed if the public are to be incorporated into the management of this species. Commercial fishers highlighted the potential impact *C. japonica* may have on the flatfish fishery, an area requiring further investigation. Further research on the impacts *C. japonica* could have on other species of ecological, social, cultural and economic importance in NZ is required.

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Shannon Weaver

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1. Introduction

Crabs are highly successful invaders (Hänfling et al., 2011; Fowler et al., 2013) exhibiting a suite of biological traits common to *r*-selected species (high fecundity, early sexual maturity and rapid growth rates) and considered indicative of successful invaders (Weis, 2010). Introduced crabs are often quick to form high densities and exhibit competitive advantages over resources with local fauna (Brockerhoff and McLay, 2011). Three families stand out as particularly notorious invaders: Grapsidae (shore crabs), Majidae (spider crabs) and Portunidae (swimming or paddle crabs), the latter comprising some of the most successful species at establishing in new environments (see Brockerhoff and McLay, 2011). Well recognised Portunidae invaders include species from the genera *Callinectes*, *Carcinus*, *Charybdis* and *Portunus*, and are typically identifiable by the posterior set of paddle-like appendages that make them agile swimmers (Browne and Jones, 2006).

Charybdis japonica (A. Milne-Edwards, 1861) (Crustacea: Decapoda: Portunidae) was first discovered in New Zealand (NZ) in Waitematā Harbour, Auckland, in 2000 (Webber, 2001). This is the first successful establishment of *C. japonica* outside of its native range of East Asia. Discoveries of *C. japonica* have also occurred in Australia (Adelaide, South Australia 2000; Peel-Harvey Estuary, Western Australia 2010, and the Swan River Estuary, Western Australia 2012) and the Mediterranean Sea in 2006 (Froggia, 2012). However, these incursions have not yet led to established populations (Hooper, 2001; Hourston et al., 2015). It is most likely that *C. japonica* was transported to NZ as larvae (Miller et al., 2006; Ahyong and Wilkens, 2011) in ballast water (Smith et al., 2003; Gust and Inglis, 2006; Fowler et al., 2011). Despite the commercial importance of *C. japonica* throughout its native range (Liu and Cui, 2010), limited biological and ecological knowledge existed prior to the NZ incursion, warranting focused research in NZ. This introduction provides a unique opportunity to study the early invasion dynamics of this species.

New Zealand's crab fauna has a low representation of portunids (of 136 Decapoda endemic to NZ, there are 77 Brachyuran species of which seven are portunids; Dell, 1968; McLay, 1988; Gordon et al., 2010). There are concerns that *C. japonica* may compete for food (Archdale et al., 2007; Fowler et al., 2013) and habitat (Fowler, 2011) with NZ's only similarly sized native portunid paddle crab, *Ovalipes catharus* (White and Doubleday, 1843).

Both species occur in estuaries and harbours, though *O. catharus* only utilises these habitats during juvenile stages and reproduction (both times of high vulnerability to predation for *O. catharus*). Fowler (2011) suggests predation of juvenile and adult *O. catharus* by *C. japonica* may occur, with this opinion substantiated by Townsend et al. (2015), whereby multiple species of native crabs were confirmed as a significant dietary component of *C. japonica*. *Charybdis japonica* may have a further advantage in that this species might be able to maintain a hard shell during mating, potentially reducing its vulnerability to predation (Inglis, 2013). *Ovalipes catharus* predominantly occupies shallow, sandy beaches throughout NZ (Wear, 1982; Osborne, 1987; McLay, 1988), whereas *C. japonica* appears more versatile in habitat use, occupying muddy, sandy, or rocky areas and are also associated with macroalgae and seagrass habitats (Browne and Jones, 2006).

Parker et al., (1999) identifies three dimensions for evaluating the total ecological impact of an introduced species as:

- 1) Range (the area in which an introduced species occurs);
- 2) Abundance (the biomass of individuals within that range); and
- 3) Per capita impact (biological specifics at the individual scale).

It is also important to take into consideration the spatial and temporal fluctuations that are possible across all three of these dimensions (Parker et al., 1999). In NZ, many of these aspects have begun to be addressed for *C. japonica* over the last decade (see Gust and Inglis, 2006; Miller et al., 2006; Fowler et al., 2011; Fowler et al., 2013; Townsend et al., 2015). The socio-economic impacts

that *C. japonica* may have are yet to be investigated despite concerns expressed within the literature (Fowler 2011; Townsend et al., 2015). Fowler (2011) highlights the scientific value fishers have in the ability to perceive the dynamics of both *O. catharus* and *C. japonica* within the areas they fish. The experience crab fishers have accumulated over time (in the form of non-traditional ecological knowledge) may provide valuable insight for understanding and managing the introduction of *C. japonica* in NZ.

Ojaveer et al. (2015) emphasises that the full scope of impact includes environmental, economic, social and cultural aspects. Socio-economic impacts can result from introduced species affecting the supply of environmentally sourced goods and services utilised by people (Reaser et al., 2007). Non-use values, such as intrinsic and persistence values, are also under threat (Barbier et al., 2011). Worldwide, marine introduced species have had negative impacts on infrastructure, tourism, ecosystem and human health, aquaculture and fisheries, including land- and water based recreational activities (see Bax et al., 2003; Campbell, 2008). Cultural impacts include effects on various aspects such as family engagement and traditional harvesting opportunities, particularly the culturally valuable aspects of artisanal fisheries associated with cultural identity (Campbell, 2008; Pejchar and Mooney, 2009; Campbell and Hewitt, 2013; Mach and Chan, 2013). The effects caused by introduced species are typically assessed as negative impacts, but may also include positive effects that provide benefit (see Bax et al., 2003; Rodriguez, 2006; Steer, 2015). Without a comprehensive assessment of the effects across all core values (environmental, economic, social and cultural), the risks, or benefits, posed by a non-native species are, for the most part, incomplete.

1.1 What are introductions

Coastal, shallow water systems are areas of considerable human modification, making them amongst the most highly impacted ecosystems worldwide (Hassan et al., 2005; Lotze et al., 2006; Halpern et al., 2008; Crain et al., 2009; Airoldi and Bulleri, 2011). Many coastal systems (e.g., harbours, embayments and estuaries) act as important nursery grounds for a wide range of marine species (Morrison et al., 2009; Barbier et al., 2011). Increasing urbanisation and exploitation, as well as increased tourism and trade-related traffic, cause a variety of effects such as degraded water quality, pollution, and over-exploitation of fisheries, significantly altering the complex abiotic systems and biotic assemblages present in these environments (Barbier et al., 2011). A degraded ecosystem has a reduced resilience and potential susceptibility to further change, such as the successful establishment of non-native species (Lovell and Stone, 2005). As the global trade of goods via air, land and sea increase, many organisms have the unintentional opportunity to 'hitchhike' and spread into new geographic areas and ecosystems (Carlton, 1985; Carlton, 1989; Ruiz and Carlton, 2003). These range expansions are well beyond distances species could reach by natural means (Carlton, 1985; Hewitt et al., 2004b).

Though the accidental arrival of species may constitute a large proportion of introductions, species can also be introduced intentionally (for example, for aquaculture purposes; Hewitt et al., 2006). The consequences of any introduction, in both a human and wider environmental context, can fall anywhere along a scale of advantageous (e.g., Rodriguez, 2006; Bertness and Coverdale, 2013) to disadvantageous (e.g., Pimentel et al., 2000; Mack et al., 2000; Pimentel et al., 2005; Simberloff, 2011). The latter grouping is commonly termed as 'invasive species' and are considered as species that rapidly colonise and spread (Richardson et al., 2000; Colautti and MacIsaac, 2004; Occhipinti-Ambrogi and Galil, 2004 in Ricciardi and Cohen, 2007) and/or species that have caused –or are thought to potentially cause in the future- environmental, economic and social impacts (Ricciardi and Cohen, 2007).

An ongoing debate exists around the extensive terminology for introduced species. The term 'invasive' alone has at least five different definitions (see Colautti and MacIsaac, 2004). It is important to note that both native and non-native species can establish and proliferate in novel areas (i.e., any species can exhibit invasive characteristics regardless of place of origin; Colautti and MacIsaac, 2004; Warren, 2007). The terminology within this thesis will utilise the terms 'introduced' and 'non-native' interchangeably as they do not connote that there is a proven or perceived impact, they only suggest a species has reached an area outside of its previously known native range via anthropogenic transfer.

The global movement of species is leading towards a homogenisation of landscapes (McKinney and Lockwood, 1999). This great mixing of species, aptly termed 'species shuffling' by McNeely (2001), will continue to alter the biodiversity of the planet. Warren (2007) suggests this represents a shift toward the very opposite of biodiversity by leading to a 'biosimilarity' worldwide. Authors such as McNeely (2001) and Wilson et al. (2016) emphasise the human dimension within the global problem of introduced and invasive species, acknowledging the role humans play in the introduction, establishment and response mechanisms that constitute invasions. There is a growing concern from scientists (Schmitz and Simberloff, 1997), environmental managers (Rilov and Crooks, 2009) and the public (Carlton, 2003) regarding biological invasions as occurrences multiply and awareness of the (often irreversible) impacts increase (Chapman et al., 2001).

The difficulties of effective control after a species has invaded has become evident in many situations, particularly in marine environments (Bell et al., 2008; Galil et al., 2014; Ojaveer et al., 2015). Examples exist where marine species have invaded and subsequently been eradicated (e.g., Willan et al., 2000; Hewitt, 2003; Hewitt et al., 2005; Bell et al., 2008), but these are rare (Hewitt et al., 2004b). Often a species arrives in a new location and remains undetected until it is too late to eradicate (e.g., Campbell and Hewitt, 2013) or eradication is attempted but fails (e.g., Hewitt et al., 2005). The impacts of invasions are sometimes slow to manifest, often resulting in subtle changes being witnessed

through time. In many instances the changes are frequently viewed in isolation, overlooking the problem in a wider ecological context (Low, 2001). Direct impacts to endangered or charismatic species tend to garner attention more readily than the incremental changes in ranges and abundances (or ecological processes) common with invasions (Simberloff et al., 2013). In addition to all this, changes are profoundly more difficult to witness within marine systems in comparison to those on land (Bax et al., 2003; Simberloff et al., 2013).

Both the introduced species and the receiving environment contribute to the success (or failure) of a species in a new area (Fowler, 2011). Certain biological and ecological characteristics aid successful establishment in marine environments, such as broad environmental tolerances (e.g. temperature and salinity), high fecundities and short life spans (Lodge, 1993). Highly tolerant organisms are more likely to survive extended journeys, hence these species have a higher chance of establishing in new areas (Maclsaac et al., 2002). In terms of the receiving environment, factors such as resource availability, species assemblages already present, and competition for resources will influence the success of an introduced species (Bruno et al., 2003; Dunstan and Johnson, 2007). Estuarine environments, in particular, appear to show higher occurrences of introduced invertebrates in comparison to open coasts (Preisler et al., 2009). The reasons for this include:

- 1) A higher propagule pressure in estuaries;
- 2) Higher retention of larvae;
- 3) Lower levels of biotic interaction (i.e. competition);
- 4) Availability of empty niches due to anthropogenic alteration; and
- 5) “Depauperate and geologically young estuarine assemblages” (Preisler et al., 2009 p. 615)

1.2 Introduced species in New Zealand

The antipodean isolation from other major landmasses has resulted in the unique biotic assemblages found throughout the land and waters of NZ. New Zealand has also experienced relatively recent human colonisation in contrast to the Northern Hemisphere, where the movement of people between settlements has occurred over a much longer period (Crosby, 1986). This isolation limits the ability of many species successfully reaching and establishing on islands by natural means (The island biogeography theory; Elton, 1958; MacArthur and Wilson, 1967). It is estimated that the bulk of introduced marine species have arrived in to NZ in the last 200 years (Ahyong and Wilkens, 2011). New Zealand knows well the impacts invasions can have on land (e.g., possums, stoats, rats and rabbits; King, 1984; Jay and Morad, 2006; Goldson et al., 2015) and has undergone a fundamental shift in the way flora and fauna is conserved over the centuries (Jay et al., 2003; Steer, 2015).

During the 19th century, conservation in NZ largely focused on the protection of species demonstrating economic value, whether native or not (e.g., game species; Star, 1997; Jay et al., 2003). This led to many intentional introductions (such as species introduced by acclimitisation societies; see Jay et al., 2003; Steer, 2015), and the marine environment was not excluded from this (discussed further below). Throughout the 20th century to the present day, a rise in tourism interest in the unique, endemic biodiversity of NZ has warranted heightened protection (Jay et al., 2003; Steer, 2015). Native biodiversity is now a considerable aspect of NZ's national identity demonstrating cultural, social and financial values (Patterson and Cole, 1999; Morad and Jay, 2003; Jay and Morad, 2006; Steer, 2015). Both native biodiversity and pest eradication are considerably lucrative industries, the former estimated to generate revenue of NZ\$920 million per annum (DoC, 2006), with the pest eradication industries being a multi-billion dollar industry worldwide (Pimentel et al., 2000).

New Zealand's marine resources hold a significant presence in Māori culture and spirituality. As a nation of islands, many people live in coastal areas and

recognise the ocean as an integral aspect of their communities (Barbera, 2012). Fishing and harvesting of marine resources, as well as the ability to provide food, has a significant cultural importance to Māori, as it does to many New Zealanders (Barbera, 2012). One (albeit small) example of the combined cultural and economic importance of native species in NZ is the representation on every modern denomination of NZ's bank notes (Steer, 2015).

Within the marine environment, at least 177 introduced species have successfully established in NZ waters (Gordon et al., 2010). Species arrivals to NZ are mainly attributed to hull fouling on vessels, with a small proportion of incursions attributed to ballast water (Cranfield et al., 1998). Coutts and Dodgshun (2007) argue that sea chests (recesses in a vessel's hull housing water intake pipes) facilitate species dispersal to NZ more so than ballast water or hull fouling. This is largely due to sea chests being habitats that transport adult mobile organisms, with hull fouling and ballast water the main carriers of encrusting organisms and larvae respectively (Coutts and Dodgshun, 2007). Cranfield et al. (1998) have highlighted factors that contribute specifically to the establishment of introduced marine species;

- 1) Repetitive introduction of species;
- 2) Enclosed nature of the receiving environment; and
- 3) The introduced species attributes.

Introduced marine species to NZ include algae, molluscs, crustaceans and are commonly discovered within harbour environments (Cranfield et al., 1998). Harbours provide a sheltered, low energy environment that can retain introduced larvae due to reduced dispersal opportunities as circulation and water exchange may be limited (Cranfield et al., 1998). Shipping ports are also typically located within harbours, which receive high levels of local, national and international boat traffic. In the past, many attempts at introducing species of economic value have occurred in NZ (Cranfield et al., 1998). All marine organisms introduced intentionally for fisheries in NZ have failed to establish, with the exception of one species, the Pacific salmon (*Oncorhynchus tshawytscha*;

Cranfield et al., 1998). One example of a failed intentional introduction of a marine species for potential economic gain is *Cancer pagurus*, a crab of European origin. This species was imported in small numbers repeatedly (1885, 1907, 1908 and 1913) with large quantities of larvae released into the Otago Harbour (Thomson and Anderton, 1921). This was most likely done in an attempt to replicate the commercial fisheries of this species in Western Europe. Despite the considerable effort put in at the time the species did not successfully establish (Cranfield et al., 1998).

Ecological impacts from introduced species may become apparent in the form of habitat modification and/or competitive exclusion of detriment to native species /assemblages (e.g., Crooks, 1998). More indirect affects can also occur that alter ecosystem function such as nutrient cycling and complex food webs (Wittenberg and Cock, 2005). Indirect affects are often less visible and prove harder to quantify. Within the economic context, concern exists around the impact introduced marine species may have on vulnerable fisheries and aquaculture operations in NZ (Forest and Bird, 2002; MPI, 2015). Concern may well be justified in light of the considerable impacts that have occurred in other parts of the world (e.g. *Carcinus maenas* impacting on the *Katelysia scalarina* clam fishery in Tasmania; Walton et al., 2002) as well as the commercial fisheries of blue mussels, scallops, manila clams, hard and soft shell clams in the United States (Lovell et al., 2007). Similarly, the Black Sea invasion by the ctenophore *Mnemiopsis leiydi* is thought to have caused the collapse of the \$250 million per annum European anchovy fishery (Zaitsev, 1992).

Of the 81 introduced crustacean species that have been detected within NZ, 27 have established successfully (Ahyong and Wilkens, 2011). Historical trends of species introductions in NZ appear to follow maritime travel routes, with earlier species arriving from European origins and the more contemporary arrivals coming from the northwest Pacific region (Hewitt et al., 2004b; Hayden et al., 2009). The primary, modern day maritime trade route to NZ (based upon traffic volume) includes a circuit via east and south east Asian ports (Hewitt et al., 2004b). Exposure to these ports has the potential to greatly increase the

likelihood of introductions from these regions (Ahyong and Wilkens, 2011).

Many consider island ecosystems to be more susceptible to invasions than continents (Elton, 1958; Wilson, 1965; Carlquist, 1974; Perrings et al., 2002; Donlan et al., 2003), though this has been disputed by others (D'Antonio and Dudley, 1995; Denslow, 2003; Gaston et al., 2003; Inglis et al., 2006). Regardless of opinion, it is clear that endemic species are under considerable threat in NZ, due to their small geographic ranges and restricted ability to relocate/ expand their range (Inglis et al., 2006). Dalmazzone (2000) and Perrings et al. (2002) have highlighted that island nations generally represent small economies geared towards primary production with a high reliance on importing goods. A reliance on imported goods increases the opportunity for introduced species to arrive into island ecosystems (increased propagule pressure; Perrings et al., 2002).

The unique and endemic species assemblages of NZ result in a reduced number of functional groups. This results in “empty” ecological niches that are relatively devoid of predators, competitors and pathogens, which introduced species can readily fill (the ‘vacant niche hypothesis’; Elton, 1958; MacArthur and Wilson, 1967; Carlquist, 1974; Towns and Ballantine, 1993; Sax and Brown, 2000). Within the marine environment alone, around 150,000 empty niches are estimated worldwide (Walker and Valentine, 1984). In contrast, naïve native species may not have evolved under situations of considerable competition for resources due to low species diversities and therefore may lack defensive mechanisms and behaviours (Elton, 1958; Simberloff, 1995). Introduced species may possess an additional advantage in ‘leaving behind’ predators, parasites and diseases of their native regions when introduced to novel areas (The enemy release hypothesis; Torchin et al., 2003).

Quantifying the effects of species invasions are often considered difficult due to a lack of data pre-invasion (Strayer et al., 2004; Snyder and Evans, 2006; Occhipinti-Ambrogi, 2007; Guiasu, 2016). The invasion of *C. japonica* into NZ waters provides a unique opportunity as:

- 1) This is the first recorded establishment of *C. japonica* outside of its native range;
- 2) NZ's lack of a permanent estuarine dwelling portunid has created an opportunity to explore the vacant niche hypothesis; and
- 3) Catch records for commercially important native species that are suggested to be affected by *C. japonica* exist pre- and post-invasion.

1.3 *Charybdis japonica*- the introduced portunid

Charybdis japonica (Figure 1) is native to the coastal waters of China, Japan, Korea, Taiwan, Malaysia and Indonesia where it is a commercial and traditional fishery (Sakai, 1976; Smith et al., 2003; Ng et al., 2008). It is known by a number of common names such as the Asian paddle crab, Japanese swimming crab, lady crab, or 'Ishigani' in Japanese. Indonesia represents *C. japonica*'s southern limits based on biological tolerances, with it's northern boundary extending as far as Peter the Great Bay, Russia (Kolpakov and Kolpakov, 2011). This native range spans a latitudinal gradient of approximately 35°, thereby requiring wide tolerances and plasticity to changes in temperature, salinity etc. (Tooman, 2008). It's southern boundary has now extended to NZ, where it was found by commercial fishers in 2000 (Webber, 2001).

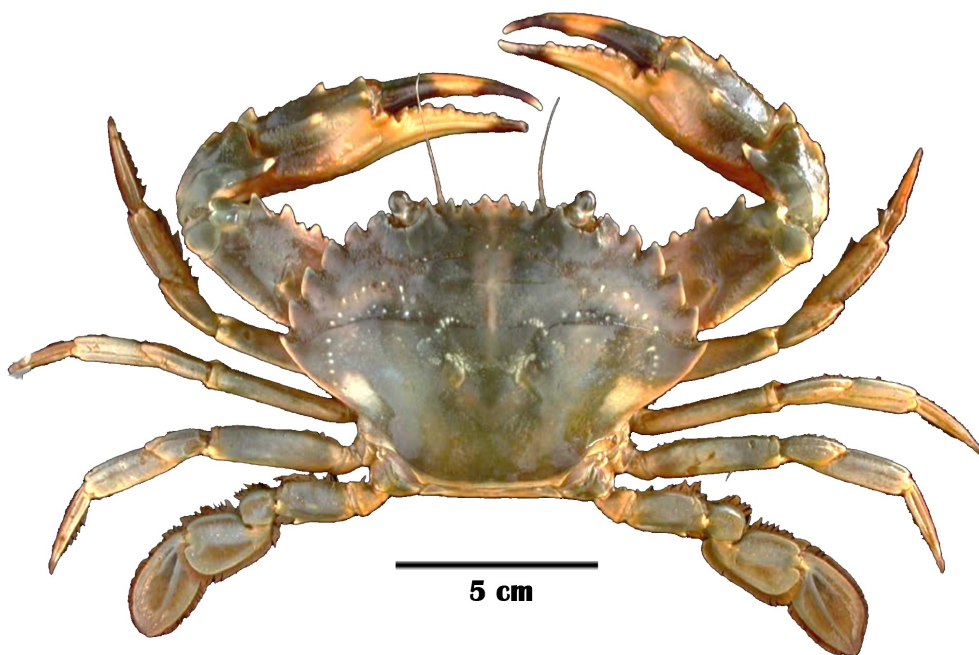


Figure 1. *Charybdis japonica* (Ahyong and Wilkens, 2011).

Charybdis japonica inhabits near shore environments comprised of mud, sand or stony substrates to a depth of approximately 15m in both it's native and introduced ranges (Wee and Ng, 1995; Kim, 2001; Gust and Inglis, 2006).

Charybdis japonica is commonly found around man-made structures such as channel markers and wharf posts. Tooman (2008) suggests this association may

be due to the abundance of encrusting prey species (such as the Pacific oyster, *Crassostrea gigas*) that can be found on submerged structures. This species is considered a generalist predator, with Jiang et al. (1998) and Weimin et al., (1998) demonstrating that Chinese populations of *C. japonica* prey on mussels, clams, crustaceans (including cannibalism), fish and cephalopods. A generalist diet was also confirmed for the NZ populations by Tooman (2008) and Townsend et al. (2015). Despite the importance of *C. japonica* as a commercial fishery resource in its native range, a lack of readily available information prior to its arrival in NZ, has prompted increased research on this species since 2000 (Figure 2). Basic biological and ecological characteristics (for example, dietary and habitat preferences) are crucial in determining the impacts this species may pose to coastal regions in NZ.

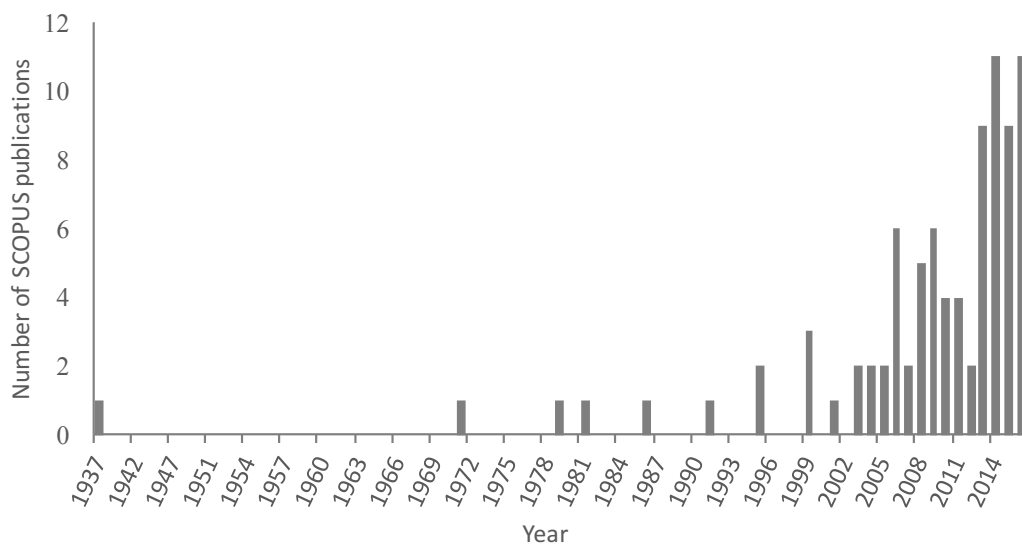


Figure 2. SCOPUS publications on *Charybdis japonica* over time, search term “*Charybdis japonica*”.

Charybdis japonica can reach up to 116mm carapace width (Kolpakov and Kolpakov, 2011). Carapace width is the common measurement for Brachyuran size given that the abdomen is tucked under the ventral surface rendering total length measurements inappropriate (hereafter referred to as ‘CW’; Stevens, 1999). Males grow to a larger size than females (Kolpakov and Kolpakov, 2011). Males are thought to live slightly longer than females, reaching 4 and 3.5 years respectively (Kim, 2001). The mottled colouring on the carapace and appendages

can vary considerably however, *C. japonica* is still readily distinguishable from other species of *Charybdis* that co-occur in its native regions. Colour morphs range from cream and pale green to purple-brown with many of the NZ specimens having yellow-orange markings on the chelae (Smith et al., 2003). Other morphological characteristics distinct to *C. japonica* include sharp spines along the carapace and palm of the chelae and pilose natatory (paddle) legs (Smith et al., 2003). These characteristics along with the highly aggressive nature of *C. japonica* distinguish it from *O. catharus* in NZ (Webber, 2001).

Reproduction is considered to be bimodal in China (Wang et al., 1996)., Spawning occurs when sea temperatures are within the range of 20-28°C (Wang et al., 1996). Females may produce multiple egg batches per year with an average of 85,000 eggs per brood (Wang et al., 1996). Higher fecundities have been observed in Russian populations of *C. japonica* (571,300 eggs on average; Kolpakov and Kolpakov, 2011) and in NZ populations (upwards of 400,000 eggs per brood; Fowler and McLay, 2013). Sexual maturity is reached at 50mm CW in its native range (Yu, 2005). In NZ, *C. japonica* has been observed to reach sexual maturity at smaller sizes (Wong and Sewell, 2015). Female moulting prior to reproduction, as seen in other portunid species such as *O. catharus*, was assumed to also occur in *C. japonica* yet there are suggestions mating in hard shell may be possible for this species (Inglis, 2013).

Charybdis japonica is known to be a host of the White-Spot Syndrome Virus, which poses a serious threat to many crustaceans, causing extremely high mortalities within days of contracting the disease (Lightner, 1996; Maeda et al., 1998). The NZ established populations do not appear to have this virus (Miller et al., 2006). Miller et al. (2006) found a distinct lack of parasites in the NZ population of *C. japonica*, considered to be another advantage to rapid expansion into a new area (Torchin et al., 2003; Tooman, 2008). The enemy release hypothesis suggests that a lack of parasites and pathogens allow an introduced species to reallocate resources towards other aspects, such as increased reproductive output, growth and development.

Charybdis japonica possess a range of traits synonymous with successful invaders such as high fecundity, early sexual maturity, broad environmental tolerances (in both salinity and temperature) and a large native range (Fowler, 2011). It is also a highly aggressive crab, providing a competitive advantage over securing resources (food and habitat; Fowler, 2011). This behavioural trait is considered to have developed due to intense competition within the diverse crab fauna throughout its native range (61 *Charybdis* species in the Indo-West Pacific region alone; Ng et al., 2008; Tooman, 2008; Fowler, 2011). Concern is expressed by many over the impact this species could have on bivalve populations and the only similarly sized native portunid crab, *O. catharus* (Gust and Inglis, 2006; Tooman, 2008; Townsend et al., 2015; Wong et al., 2016). *Charybdis japonica* has shown a distinct advantage in gaining possession of a food resource over *O. catharus*, regardless of which crab initially held possession (Fowler, 2011).

Fowler (2011) suggests that interactions between these two species will most likely occur due to large dietary overlaps. It is unclear at this point if *C. japonica* is also exhibiting a spatially competitive advantage over *O. catharus* (i.e., via exclusion from habitat or active avoidance) though elsewhere in the world, superior competitor crab species have been shown to limit the distributions of other crabs (Lohrer and Whitlatch, 2002; Hunt and Behrens Yamanda, 2003; Belair and Miron, 2009; Breen and Metaxas, 2009; Fowler, 2011).

Since its arrival to NZ in 2000, *C. japonica* has spread throughout northern NZ, and was most recently discovered in Kaipara Harbour on the west coast of the North Island in 2016 (Bradstock, 2016; Figure 3). The continued spread of *C. japonica* throughout New Zealand will likely increase the chance of competitive interactions and may potentially lead to a significant displacement of *O. catharus* (Fowler et al., 2013). CABI (2012) have summarised the potential ecological and socio-economic impacts of the *C. japonica* invasion (Table 1).

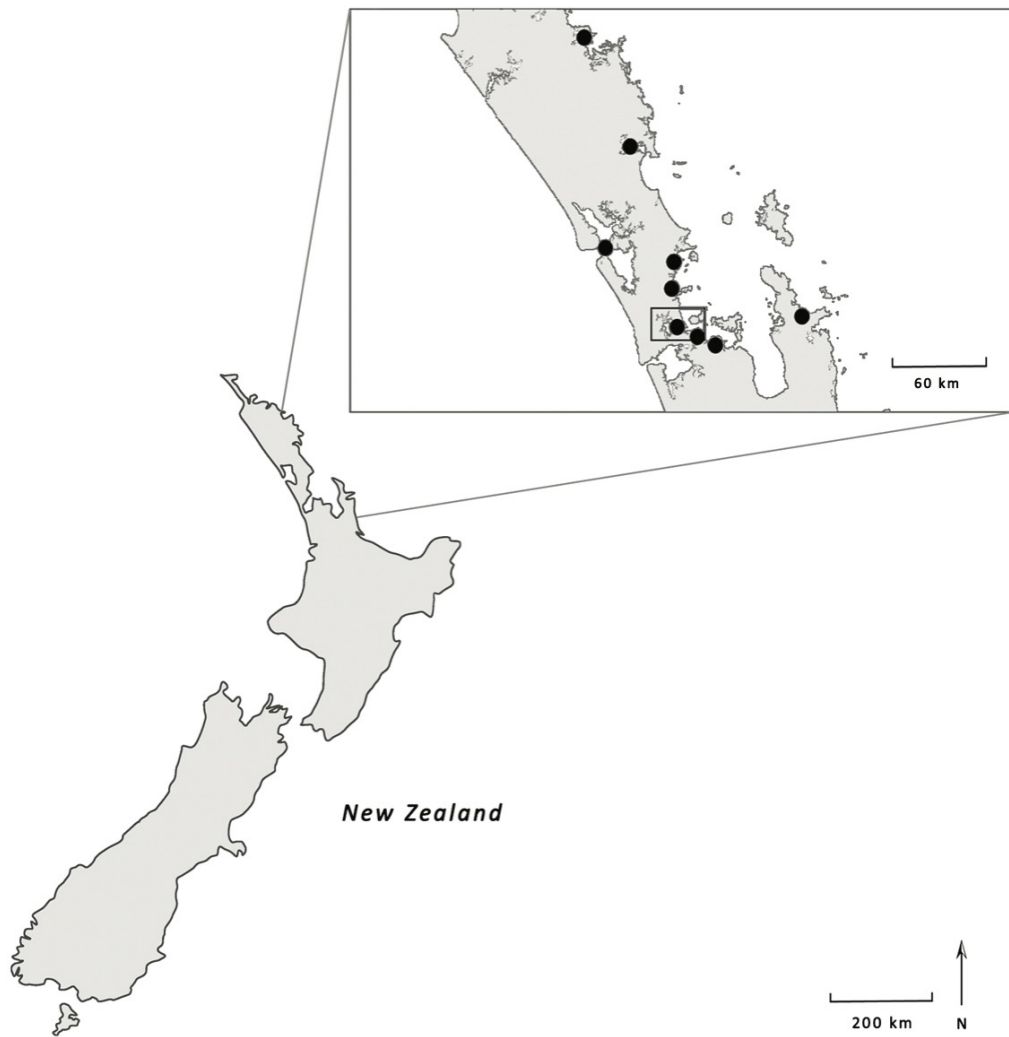


Figure 3. Confirmed occurrences of *Charybdis japonica* throughout Northern New Zealand represented as black dots. Boxed area in inset showing the site of introduction, Waitematā Harbour (modified from Townsend et al., 2015).

Table 1. The impact factors specific to *Charybdis japonica* invading in to new regions (modified from CABI, 2012).

Impact dimension	Impact outcomes	References
Ecological	Ecosystem change/ habitat alteration	Townsend et al. (2015)
	Modification of natural benthic communities	Gust and Inglis (2006); Townsend et al. (2015)
	Reduced native biodiversity	Fowler (2011); Townsend et al. (2015)
	Threat to/ loss of native species	Fowler (2011); Galil et al. (2011); Townsend et al. (2015)
Socio-economic	Negatively impacts aquaculture/ fisheries	Archdale et al. (2007); Ahyong and Wilkens (2011); Fowler (2011)
	Negatively impacts cultural/ traditional practices	Browne and Jones (2006)
	Negatively impacts livelihoods	Browne and Jones (2006)

1.3.1 The spread of *Charybdis japonica* in New Zealand

Identifying the initial distribution and potential geographic range of introduced species are considered critical first steps in assessing possible impacts of an invasive species (Grosholz and Ruiz, 1996). Research undertaken by Gust and Inglis (2006) demonstrated that *C. japonica* had spread throughout Waitematā Harbour, Auckland and neighbouring Tamaki and Weiti estuaries (10 km southeast and 25 km north, respectively). Potential range expansion estimates by Gust and Inglis (2006) were based upon the realised niche sea surface temperatures (SSTs) that *C. japonica* occupies within it's native range and suggest that adult *C. japonica* could survive throughout NZ estuaries nationwide. Potentially, the only limiting variable being the comparatively warm SSTs common during spawning within their native range. New Zealand experiences more moderate SSTs that range from 11-21°C (Gust and Inglis, 2006).

Fowler et al. (2011) investigated how temperature and salinity tolerances of *C. japonica* larvae (Stage I zoeae) influenced the potential range expansion capability of this species in NZ. Temperature and salinity are known to greatly influence growth, development and survival for many crab species (Anger, 1991; Sulkin et al., 1996; Baylon and Suzuki, 2007; Bravo et al., 2007). Fowler (2011) demonstrated that *C. japonica* has high temperature and salinity tolerances, which would theoretically enable larvae to survive as far south as Akaroa Harbour, on the Banks Peninsula (43°48.67'S, 172°56.07'E) in the South Island of NZ.

Tooman (2008) identified a genetic bottleneck in *C. japonica* populations that occurred at the time of introduction into NZ. Despite bottlenecks usually being a limiting factor to the success of invasive species, other life history characteristics can aid in overcoming this limitation (e.g., high gametic output; Tooman, 2008). It is evident that the establishment of *C. japonica* in NZ has not been hindered by this reduction in genetic diversity as it possesses many life history traits that make it an ideal invader (Tooman, 2008).

By 2010, *C. japonica* were found in significant numbers within Whangarei Harbour approximately 150km north of the initial invasion point, Waitematā Harbour. Wong et al. (2016) suggest that *C. japonica* did not spread north to Whangarei harbour from Waitematā harbour as a secondary invasion, but that the Whangarei harbour was a separate introduction entirely. This deduction is based upon the prevailing ocean current dynamics in north eastern NZ and because Whangarei receives shipping directly from Japan (Wong et al., 2016). Wong et al. (2016) infers that 16 years post-invasion, the full impact of *C. japonica* is still not fully realised.

Charybdis japonica is actively monitored via a NZ-wide marine surveillance programme (The Marine High Risk Site Surveillance Programme (MHRSSP)) that commenced in 2002. Surveillance occurs bi-annually (winter and summer) in NZ's 11 main ports and harbours. The primary focus is on Unwanted Organisms (species recognised as being introduced and in need of management under the

Biosecurity Act 1993; <http://www.biosecurity.org.nz/species-information/>). The secondary focus of the surveillance efforts is on introduced marine species not listed under the Unwanted Organisms Register and to record their range expansions. *Charybdis japonica* falls into the latter category (commonly termed 'non-target species') and is sampled via a range of methods (typically non-selective trapping) at multiple sampling locations within the 11 port locations. As a consequence to the non-selective trapping methods, both *C. japonica* and *O. catharus* are caught and subsequently recorded. The record of the fluctuating populations of both species at Waitematā and Whangarei harbours spans 12 years. Based on these records (MPI, unpublished data), catch rates are seen to fluctuate considerably, with both ports showing a negative correlation with *O. catharus* catches reducing as *C. japonica* catches increase (Figures 4 and 5). This data could infer a potential biological impact from the *C. japonica* invasion. Yet, the variability in the data is high and it may in fact be 'noise' in the biological system rather than a cause and effect relationship.

A fish-down eradication trial was conducted by Golder Associates (2008) for the *C. japonica* population situated in Turanga Creek, Auckland (an estuary that feeds into Waitematā Harbour, where *C. japonica* was first discovered). This trial did not prove successful as *C. japonica* returned to original population levels in the nine months following the trial (Golder Associates, 2008). Failure was predominantly attributed to continual recruitment of crabs from the larger population throughout Waitematā Harbour. Golder Associates (2008) suggests an integrated pest management (IPM) strategy incorporating multiple control methods would be required to manage introduced marine crustacean incursions in NZ.

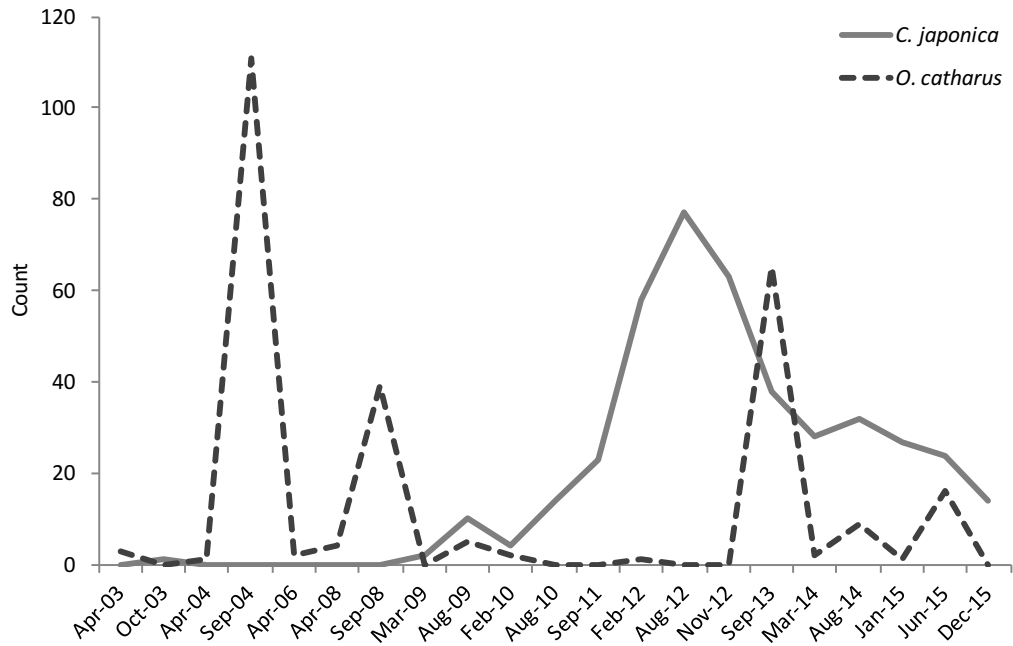


Figure 4. Catch rates from MHRSSP surveys, Whangarei Harbour, Northland (MPI, unpublished data).

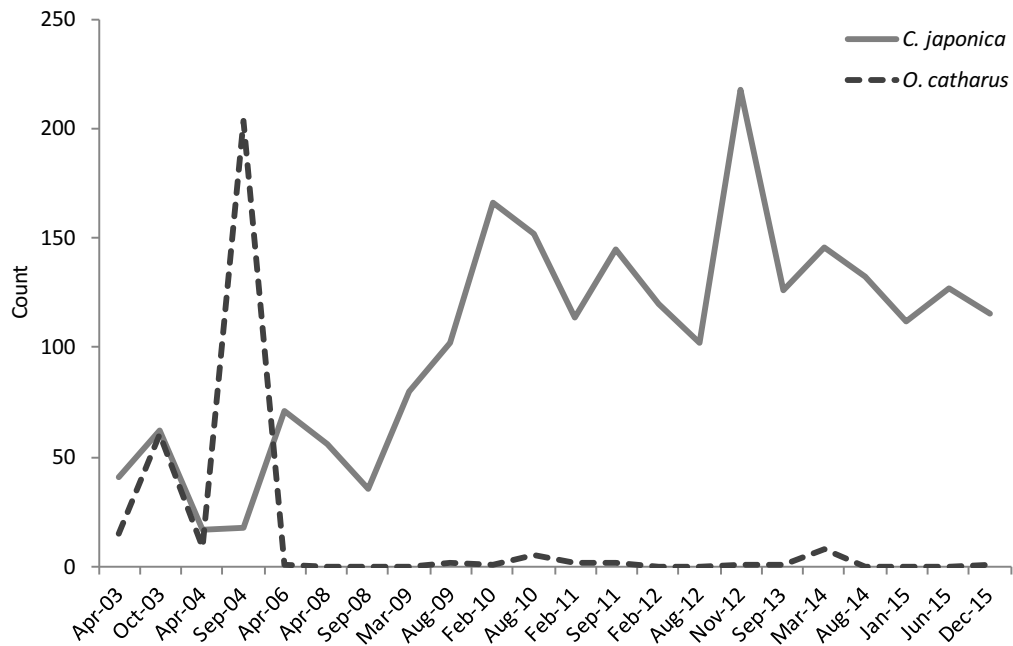


Figure 5. Catch rates from MHRSSP surveys, Waitematā Harbour, Auckland (MPI, unpublished data).

1.4 *Ovalipes catharus*- the native portunid

Ovalipes catharus (Figure 6), commonly termed paddle crab, swimming crab or pāpaka in Māori (a common term encapsulating both freshwater and marine crabs), is a portunid crab species native to NZ and Southern Australia. It is common in sandy, shallow coastal water habitats, from intertidal zones to ~10m in depth (Stead, 1983; McLay and Osborne, 1985; Wear, 1988). *Ovalipes catharus* are thought to live for 4-5 years reaching a maximum CW of 150mm, though average size is around 130mm/ 500g (Osborne, 1987). They are a sexually dimorphic species, with typically larger males than females (Stevens, 1999). Flattened ventral legs enable this species to swim and burrow into sand. This behaviour enables them to source food and evade predators (McLay and Osborne, 1985).

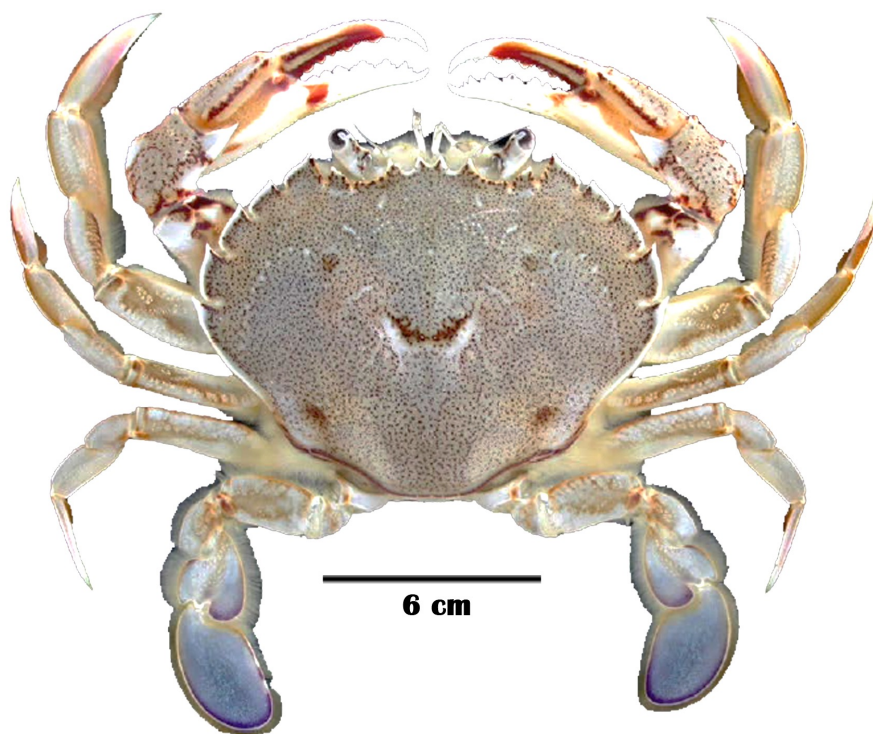


Figure 6. *Ovalipes catharus* (Ahyong and Wilkens, 2011).

Ovalipes catharus are most active at night, when they emerge from burrows to search for food. *Ovalipes catharus* are regarded as generalist predators and important scavengers within sandy coastal systems, although they are suggested to predominantly consume bivalves such as tuatua (*Paphies subtriangulata*), pipi

(*P. australis*) and toheroa (*P. ventricosa*) (Wear, 1984; McLay and Osborne, 1985). Predators of *O. catharus* include more than 30 commercially important fish species such as snapper (*Pagrus auratus*), groper (*Polyprion oxygeneiosis*) and rig shark (*Mustelus lenticulatus*). Morphologically, *O. Catharus* possesses a more circular carapace and less prominent spines in comparison to *C. japonica*. The spotted, pale brown colourings of the carapace aid in providing camouflage against a sandy bottom (McLay and Osborne, 1985).

Ovalipes catharus migrate to harbours and sheltered bays during winter (June-August) to breed (Wear, 1984; Osborne, 1987). *Ovalipes catharus* breed with the female in soft shell stage (post moult) and copulate for up to 4-5 days (Haddon and Wear, 1993). Males carry and guard the females for approximately one week pre-moult to after copulation providing protection from cannibalism during this vulnerable morphological stage (Haddon, 1994). Fertilised eggs are attached to the pleopods on the ventral side of the abdomen where they are incubated until hatching (Osborne, 1987). High fecundity is apparent in the large amounts of eggs produced per female (approximately 500,000 eggs for a 100mm CW female; Haddon, 1994) and multiple batches of eggs produced per year (Osborne, 1987; Haddon and Wear, 1993).

Females are thought to move offshore to spawning grounds while males relocate back to open, sandy beaches to feed (Osborne, 1987). Larval development comprises eight zoeal stages and lasts around eight weeks. Larval development is thought to occur in deep offshore waters (Wear and Fielder, 1985). Larvae migrate back inshore in the final megalopa stage (Osborne, 1987). This is considered a relatively long larval period in comparison to other Portunidae (Osborne, 1987). The highly migratory nature and widespread offshore larval dispersal make it unlikely that biologically distinct populations occur. Genetic distinction could potentially occur in places such as the Chatham Islands, NZ, due to the islands isolation from mainland coastal regions (680 kms southeast of mainland NZ; MPI, 2016).

Interspecific competition may exist with other native crab species such as the red swimming crab (*Nectocarcinus antarcticus*), the cancer crab (*Cancer novaezealandiae*) and the spider crab (*Notomithrax peronii*) that co-occur with *O. catharus* in NZ. Clark (1978) has suggested that the presence of these other crabs significantly reduces the catch rates of *O. catharus*. Similarly, the presence of these other species may also influence the distribution of *O. catharus* (Armstrong, 1985).

1.4.1 The NZ paddle crab fishery

During the 1980's there was concern raised over the increased abundances of *O. catharus* and the potential impact this could have on commercially important finfish and shellfish species via predation and competition for food (Osborne, 1987). This concern led to the creation of a small inshore crab fishery (Osborne, 1987). The surge in population abundance of *O. catharus* was thought to be linked to overfishing of predatory fish species and/or "favourable hydrological conditions" (Wear, 1982; Stevens, 1999).

In the early years of the inshore crab fishery, the bulk of the commercial catch came from Tauranga, Napier and Motueka (Osborne, 1987). *Ovalipes catharus* is now predominantly caught along the northeastern coast of the North Island. This species is caught via static methods utilising a range of simple mesh crab pots containing bait as an attractant, distributed by boat (commercially) or wading from shore (recreationally). *Ovalipes catharus* was introduced into the NZ Quota Management System (QMS) on the 1st October 2002. As a fishery, the population is divided into ten stocks (Figure 7), to correspond with the ten quota management areas (QMAs) in NZs Exclusive Economic Zone. A total allowable catch for each stock is set from which commercial quota, and customary and recreational allowances are allocated (Table 2).

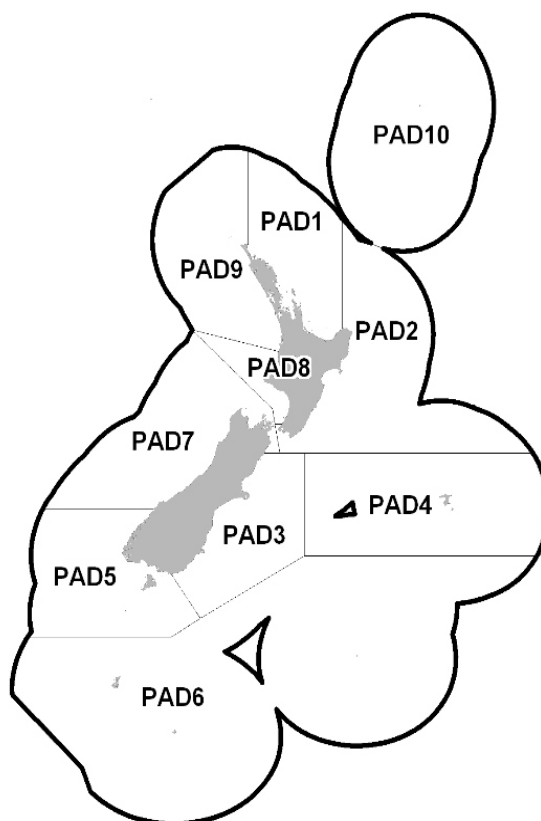


Figure 7. PAD QMAs of *Ovalipes catharus* within the NZ Exclusive Economic Zone. Image source: MPI (2016).

Table 2. Allowances (tonnes) of paddle crab per sector, per QMA. Where TACC = Total Allowable Commercial Catch and TAC = Total Allowable catch (MPI 2016).

QMA	Recreational Allowance	Customary Allowance	TACC	TAC
PAD1	20	10	220	250
PAD2	10	5	110	125
PAD3	8	2	100	110
PAD4	4	1	25	30
PAD5	4	1	50	55
PAD6	0	0	0	0
PAD7	4	1	100	105
PAD8	4	1	60	65
PAD9	20	10	100	130
PAD10	0	0	0	0

Ovalipes catharus is the only swimming crab fished recreationally in NZ (Stevens, 1999). Stevens et al. (2000) estimated the inshore crab fishery is worth approximately NZ\$1,000,000/year with landings sold to local markets instead of being exported. Total commercial landings peaked at 519 t in 1998-9 though this has decreased to around 100-150 t over the past decade (MPI, 2016). Market demands prompt the need for large crabs (> 80mm CW) commonly sold live due to the species having a short shelf life (Stevens, 1999). Whole cooked crabs and extracted crabmeat are also marketed products of this fishery (Wear 1988). The fishery is considered to only be lightly exploited (Stevens, 1999; MPI, 2016).

Recreational take is considered to be minimal (said to be “*seldom caught by recreational fishers*” in the National Marine Recreational Fishing Survey 1996; Bradford et al., 1998). It was noted during this study that specific northeastern beaches in the North Island do attract considerably high numbers of crab fishers, particularly in weekends (Weaver, *personal observation*). The recreational paddle crab fishery attracts a diverse range of people to the Bream Bay area (in Northland, NZ), the fishery is both multicultural and multigenerational. The recreational crab fishery has received increasing media attention. Concerns have been raised by local and national media over littering (RNZ, 2015; Nathan, 2015), catch dumpings (Northern Advocate, 2016), drownings (NZ Herald, 2017) and increased inshore shark sightings at popular crab fishing locations (Hampton, 2017). Safety campaigns run by WaterSafe Auckland Inc (<http://www.watersafe.org.nz/family-communities/resources-and-learning-materials/community-safety/crab-fishing/>) have urged the use of lifejackets whilst setting and retrieving crab pots after multiple drownings occurring in the area in past years (four drownings since 2011).

Customary allowance is allocated for all paddle crab stocks under the QMS though there is no recorded customary harvest for paddle crab in the Northland region (a small amount of customary paddle crab harvest has occurred in other areas of the country; M. Jones and A. Growcott, Ministry of Primary Industries (MPI), *personal communication*). This does not mean that *O. catharus* are not valued or consumed by Māori, just that the cultural importance of this species to

Māori is relatively unknown and unexplored. Despite this, some significance for this species is evident in the Tauranga region where pāpaka is recognised as taonga kai (a treasured food item; Ellis, 2014) and is represented in whakairo (wood carvings) at the Hungahungatoroa marae, located on the banks of Tauranga harbour (Figure 8). Stevens (1999) suggests that historically, *O. catharus* were not specifically targeted, and was potentially only taken during shellfish collection (i.e., as bycatch).



Figure 8. Two pāpaka featured in the whakairo (carvings) at Hungahungatoroa marae, Tauranga.

Certain commercial fishing restrictions are in place in some of the QMAs for paddle crab under the *Fisheries Regulations* 1986, although no restrictions are currently applied to PAD1, the main fishery area (Figure 9). Recreational regulations for crab fishing exist nationwide under the *Fisheries (Amateur Fishing) Regulations* 2013, which limits fishers to 50 crabs per person, per day (except for Kaikoura where only 30 crabs per person, per day is allowed). No size limits or closed seasons apply to the recreational fishery though some 'closed' areas (such as marine reserves) are located around NZ. Customary non-

commercial fishing allowance enables the taking of fish or management of fisheries for purposes consistent with Tikanga Māori (the customs and traditions of Māori culture, fundamental aspects of Te Ao Māori [the Māori world]). This excludes the taking of fish for commercial purposes and fish cannot be sold, traded or used for fundraising.

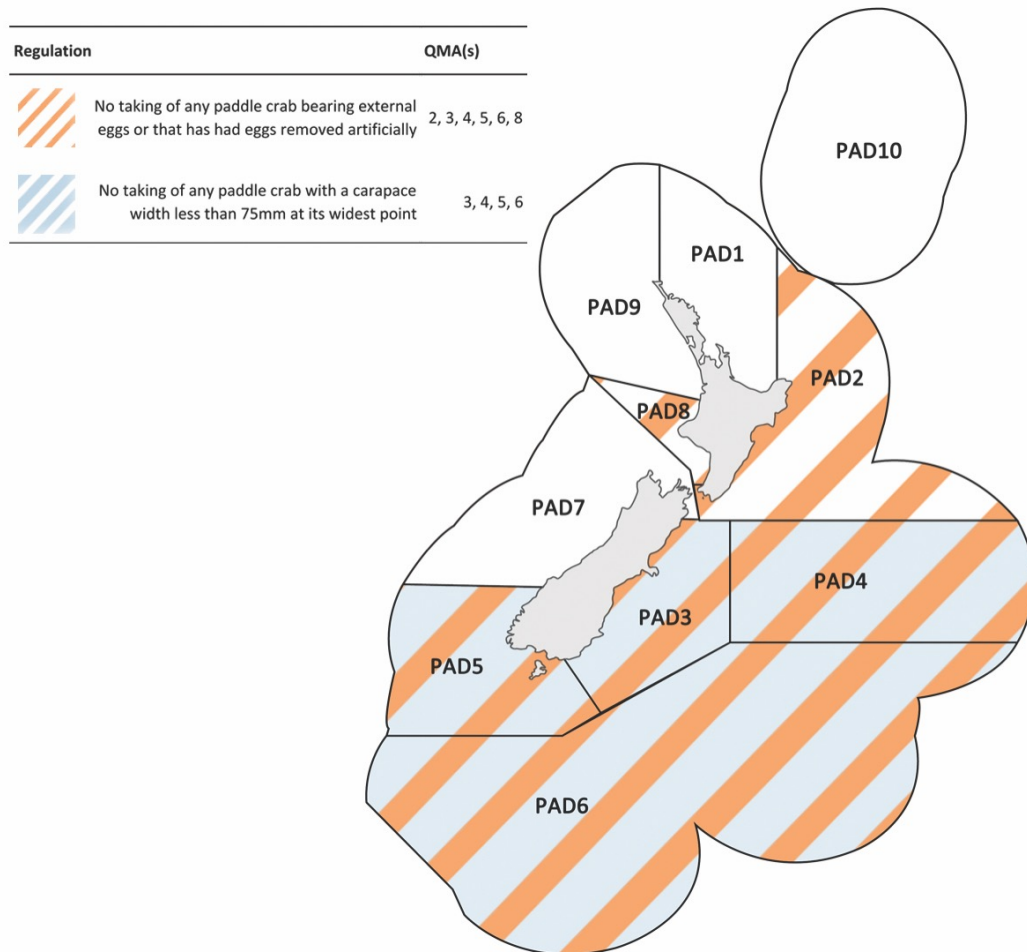


Figure 9. PADI Commercial fishery regulations under the Fisheries Act 1996.

1.5 Socio-economic and ecological interactions

A large proportion of the literature on introduced species to date has focused on ecological impacts (e.g., Parker et al., 1999; Hewitt et al., 2004a) as well as various control measures (Hewitt et al., 2004b) often without addressing the indirect impacts society experiences as a consequence of ecological impacts (Jay et al., 2003; White et al., 2008; Pejchar and Mooney, 2009). McNeely et al. (2001) consider this a very targeted viewpoint suggesting it is only likely to address the symptom of the problem. An alternative approach to impact assessment is to 'step back' and address the ultimate human causes (and consequences) behind invasions within the economic, social and cultural contexts. The social aspects of invasion science highlight an emerging line of investigation within this field addressing, for example, underlying social values towards introduced species (Foster and Sandberg, 2004), perceptions of impact to social values (Campbell, 2008; Cliff and Campbell, 2012; Campbell and Hewitt, 2013; Trenouth and Campbell, 2013) and how these perceptions can change over time (McNeely, 2001; Schüttler et al., 2011; Guiasu, 2016). Public perceptions towards introduced species can vary across cultures and can also be very organism specific (Coates, 2007; Shüttler et al., 2011).

Intrinsic links exist between ecological and socio-economic systems (Spurgeon, 1999; Baggethun and Martin-López, 2010). Social systems depend on, and are influenced by, the natural world around them (Ash et al., 2010). Within a marine context, resources provide food and income (such as fisheries), well-being (such as leisure activities) and other more indirect ecosystem services such as nutrient cycling. These benefits to humankind, since they are rarely traded as commodities, lack an observable financial value yet can have a substantial socio-economic value (Spurgeon, 1999; Barbier et al., 2011).

Bax et al. (2003) highlights that the impact on the economy "*...may be measured by the change in net social benefits caused by the introduced marine pests effect on the resource base and the added management costs*". Estimates of the economic costs of introduced species are widely cited and have been met with

some debate (such as the US study by Pimentel et al., 2000). Regardless of the exact figure, it is clear that it is always a substantial amount (in the millions to trillions of dollars per year). Applying dollar amounts to particular invasions contributes to the formulation of management tools such as cost-benefit analyses commonly used by decision makers operating within constrained budgets.

The introduction of *C. japonica* in NZ has the potential to cause impacts across core values (ecological, economic, social and cultural). The impact to *O. catharus* specifically could occur whereby ecological impacts (i.e. the competitive advantages of *C. japonica* significantly altering the *O. catharus* population) may result in socio-economic shifts in the associated fishery. This fishery comprises sectors of commercial, recreational and customary fishers all representing different stakeholder groups that have both common and unique values that are under threat by this introduction.

1.5.1 Bioeconomic theory

The theory of bioeconomics aims for an integration of ecological and economic analysis that is used to guide policy and cost effective management (Lodge et al., 2009). Kragt (2012) elaborates on this by stating;

“.. bioeconomics provides useful methods to integrate socio-economic values into biophysical analyses, improved representation of the dynamic interrelationships between natural processes and socio-economic systems [and] is needed to allow an integrated assessment of multiple values.”

There is a ‘double-edged’ validity to incorporating economic tools into biosecurity/ introduced species management when anthropogenic vectors are the driving force behind the majority of introductions. An interdisciplinary approach that incorporates biological and economic impacts aims to lead towards a higher precision in the estimates of fiscal damages caused by invasive species, both to anthropogenic and natural systems (Finoff et al., 2009). In a

broader context, bioeconomic theory may assist in the breakdown of a reductionist viewpoint of society and nature, highlighting societies complex reliance upon ecosystems and the goods and services they provide (Warren, 2007). Bossenbroek et al. (2009) has highlighted aspects of invasions that should be considered across both biological and economic disciplines:

Ecological aspects: dispersal and abundance predictions, potential habitats and establishment probability (in this case secondary spread throughout NZ).

Economic aspects: direct and indirect economic impacts, policy considerations in terms of time horizons and policy maker's behaviour.

Lodge et al. (2009) has detailed the management and policy considerations alongside the general stages of the invasion process (Figure 10). This highlights adaptation as the common human response to impacts caused by introduced species. This adaptation to change within an ecosystem prompts a change to the anthropogenic pressure on the ecosystem, highlighting the connection between nature and society in terms of feedback loops (Finnoff et al., 2009). Societal adaptations (e.g., changes in behaviour) may reduce the impact felt from introduced species whereby the damages incurred from an introduction are generally regarded as a 'new cost of doing business' (Lodge et al., 2009).

There exists similarities between economics and ecology, though they are mostly considered as bipolar research fields in terms of ideological perspectives and practice (Wam, 2010). Both are disciplines focused on limits, both examining how species manage resource scarcity (Lodge et al., 2009). Criticism exists around the ability of theories heavily focused on goods and services to effectively encapsulate non-market values of natural systems, such as intrinsic and existence values (Kragt, 2012; Muniz and Cruz, 2015). Muniz and Cruz (2015) expand on this by highlighting the eudaemonistic (capacity to produce happiness), fundamental and instrumental values nature holds. An integration of social and natural sciences is advocated by Lodge et al., (2009) to both diagnose species introductions and how to respond to them.

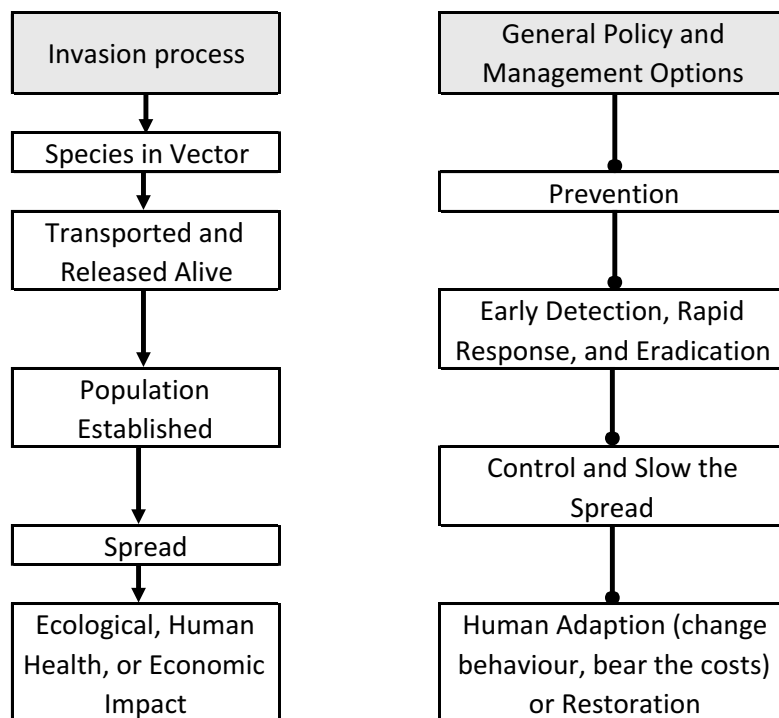


Figure 10. Invasion stages and corresponding policy and management options

(modified from Lodge et al., 2006).

1.6 Aims of this research

Research in NZ has begun to address the fundamental dimensions of ecological impact caused by *C. japonica*. Some of these studies have alluded to potential economic impacts (Gust and Inglis, 2006; Archdale et al., 2007; Fowler, 2011), yet no studies have specifically investigated the potential socio-economic impacts derived from the *C. japonica* invasions at this point in time. This study focuses on the direct impacts caused by the competitive advantages *C. japonica* has over *O. catharus* which in turn may be impacting the fishery. Many invasive species impact on native fisheries incurring significant financial losses, with equally substantial costs in any eradication/control attempts (Willan et al., 2000; Bax et al., 2003; Global Invasive Species Programme (GISP), 2008; Vilà et al., 2010). Impact upon a commercially important species provides a relatively straightforward analysis of socio-economic effect in comparison to non-market/indirect impacts.

With no significant impediment to the continued spread of *C. japonica* throughout NZ, determining the social and economic costs of this species provides a fundamental element to a risk assessment. Quantifying the risk *C. japonica* poses to NZ's coastal waters requires the analysis of past and present data to make future predictions of impacts, incorporating interdisciplinary techniques in this endeavour will elicit the most accurate outcome.

The main objective of this research is to investigate anecdotal information that *C. japonica* may be impacting upon both recreational and commercial fisheries in the invaded harbours. Specifically, this research focusses upon the impacts that may be occurring to the *O. catharus* crab fishery. Quantitative catch data trend analysis is used to determine if catch per unit effort (CPUE) changes in the *O. catharus* fishery are synonymous with the arrival of *C. japonica*. CPUE data is compared across infected and uninfected areas. In addition, qualitative interviews with fishers (commercial and recreational) were conducted to determine if users perceive change within the fishery due to *C. japonica*. To determine if changes are occurring, a series of interviews with commercial

fishers explore aspects such as changes in fishing practice that may be implemented due to high *C. japonica* abundance (e.g., changes in gear, catch reductions etc.) and the ability of fishers to accurately identify *C. japonica*.

Research aim: Investigate changes within the *Ovalipes catharus*' Northern New Zealand fishery (PAD1) and explore whether these changes are linked to the arrival of the introduced crab *Charybdis japonica*

Three research objectives are explored, as described below:

Research objectives:

- 1) Is CPUE data for *O. catharus* in infected areas showing a significant decline in comparison to uninfected areas since the arrival of *C. japonica*;
- 2) Have changes in the fishery been observed (or perceived to have occurred) by fishers across the commercial and recreational sectors and if so, what adaptations are being made to manage this change; and
- 3) Are fishers across all sectors able to accurately identify the two crab species or is more information required in the public sphere to aid with accuracy of species identification.

2. Methods

2.1 Study areas

PAD1, a QMA of the paddle crab fishery, is situated on the north-east coast of the North Island of NZ. It extends from Cape Runaway on the East Cape (37°35.12'S, 177°59.14'E) to Murimotu Island in the Far North (34°24.97'S, 173°02.90'E). This area comprises 5,510 km of coastline and extends over 240,662 km² of ocean within the NZ EEZ. This area contains both the main fishery for *O. catharus* as well as the known invaded range of *C. japonica* (excluding the most recent establishment of *C. japonica* in the Kaipara Harbour; Bradstock, 2016). Though evidence suggests offshore regions are intermittently utilised by *O. catharus*, the fishery is most active within the surf zone in shallow, coastal regions.

Charybdis japonica was initially found in the Rangitoto Channel in the Waitematā harbour and has since expanded its range and abundance north and south of this location (Webber, 2001; Gust and Inglis, 2006). Waitematā harbour is considered one of the most invaded marine environments in NZ (>60 non-indigenous species; Gust and Inglis, 2006), and coincides with NZ's largest city and busiest port. Fisheries data indicates that the majority of crab fishers in the PAD1 area fish out of Whangarei, 165 km north of Auckland. Hence, the widespread occurrence of *C. japonica* throughout Waitematā harbour has not had an observable impact on the *O. catharus* fishery. The commercial locus of the paddle crab fishery also happens to be the site of an active recreational fishery for *O. catharus* along the Bream Bay coastline. Bream Bay is a wide, sandy beach spanning 22 kms extending from Te Whara/ Bream Head to Paepae-o-Tū/ Bream Tail, with the entrance to Whangarei Harbour located at the northern end of the bay. The eastern coast of Northland experiences low to moderate wave conditions (Laing, 2000) and relatively warm seawater temperatures in comparison to the rest of NZ.

2.2 Data collection

2.2.1 Qualitative data collection

Research was conducted from December 2016- February 2017 (during the austral summer) to capture the dominant recreational fishing season of *O. catharus*. Paddle crab fishers (commercial and recreational) were specifically targeted in this study for their knowledge of the fishery and ability to witness changes over long periods of time. Recreational fishers were approached at four well-known crab fishing locations along Bream Bay (Figure 11) and asked to partake in a survey which took approximately 10 minutes to complete. All recreational crab fishers at these sites were approached to take part in this research to maximise data capture within a short time period. Although large groups of individuals were present on the beach, only 1-2 people per group actively set and retrieved the crab pots, hence only these individuals were considered genuine crab fishers. A survey questionnaire was presented electronically using iSurvey software (www.harvestyourdata.com) on iPad mini's. Information / consent sheet and survey questions are provided in Appendix A.

Commercial crab fishers were initially contacted by MPI to partake in the research, those that expressed interest were then contacted by myself, the primary investigator. Semi-structured face-to-face interviews were conducted with the commercial fishers, comprising a range of questions regarding background information, perceptions of change within the *O. catharus* fishery and knowledge of *C. japonica* (see Appendix B for information / consent sheets and interview questions). Interviews took an average of 30 minutes to complete. Interviews were audio recorded and transcribed verbatim. Seventeen iwi within the Auckland and Northland coastal regions were also contacted to partake in this research, specifically requesting if any individuals fished for paddle crab on a customary basis within their rohe/area (Appendix C). Demographics were not collected on any of the fishers, as the influence of demographic variables upon the perceptions were outside of the scope of this research. All participants in this study were offered the opportunity to enter a draw for a \$100 fuel voucher as an

incentive to take part in the research. Human research ethics approval was obtained for this research (project approval number FSEN2016-1; Appendix D).

Qualitative methodologies, such as the semi-structured interviews employed in this study, have increasingly been utilised to explore environmental phenomena in a comprehensive manner (Shüttler et al. 2011). Semi-structured interviews are considered the most appropriate method for understanding an individual's perspective as it allows flexibility to pursue threads of interest more so than a structured interview would allow (Jensen and Laurie 2016). Descriptive statistics were primarily used to analyse and summarise qualitative data. Frequency distributions were utilised for univariate analysis as well as measures of central tendency in some instances.

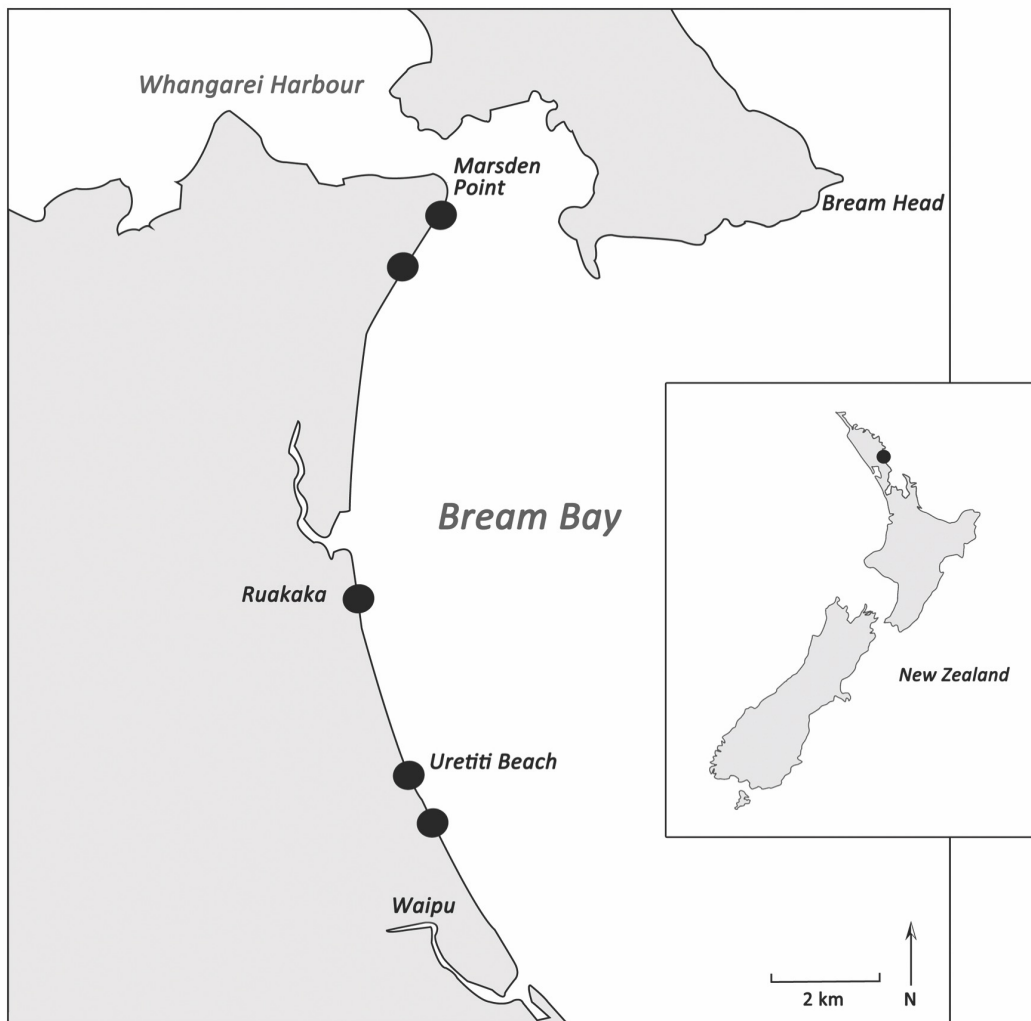


Figure 11. Recreational crab fisher survey locations in Bream Bay, Northland, New Zealand.

2.2.2 Quantitative data

Commercial fisheries catch data is publicly available from the MPI website (<http://fs.fish.govt.nz/Page.aspx?pk=7&tk=100&sc=PAD>). Catch rates for all PAD QMAs from 1989-2016 were sourced. Changes in the commercial catch history of *O. catharus* through time was analysed using parametric and non-parametric analyses. These compared mean catch rates pre- and post-incursion of *C. japonica* across the five-main fishing areas (PAD1- Auckland East; PAD2- Central East; PAD3- South East Coast; PAD7- Challenger; and PAD8- Central Egmont) to determine if differences were statistically significant ($p \leq 0.05$). Mean catch rates pre- and post-TACC introduction were also analysed to ascertain how this may have influenced the fishery. PAD QMAs that averaged less than 5 tonnes over the entire fishing history of the area were omitted from the analysis, these were PAD4, PAD5, PAD6, PAD9 and PAD10. It is likely that the PADs reporting low to no catch rates represent bycatch of *O. catharus* from other fisheries instead of representing a specifically targeted crab fishery in that area.

In a similar method to Campbell et al (2017), the ability of commercial and recreational crab fishers to accurately identify both *O. catharus* and *C. japonica* was tested by presenting a series of four crab images of which the participant chose the one they believed to be the species in question (all were crabs that can be found in NZ waters; see Appendix E). Participants were asked to identify *O. catharus* first and then *C. japonica*. To address social desirability bias, the surveys were self-administered by the participants. Potential primacy and recency, and order biases were addressed by randomising the order in which images of the species were shown for each question (note that both *O. catharus* and *C. japonica* were always present in the images presented). To reduce potential recall biases participants were only shown which species were correct after answering both identification questions. The accuracy of species identification data were analysed using Fisher's exact tests to ascertain if there was a statistically significant association between the type of crab fisher (commercial or recreational) and their ability to accurately identify *O. catharus* and *C. japonica*. Fisher's exact tests were used in this analysis due to small sample sizes.

3. Results

Results are presented for the commercial and recreational sectors as no response was gained from customary crab fishers. A lack of response is likely to be explained by recorded customary data. This suggests that *O. catharus* has not been taken as customary catch from 1998 to the present day in the study area (though small quantities of paddle crab have been taken customarily in other areas of the country; M. Jones and A. Growcott, MPI, *personal communication*). Kina, crayfish and paua appear to constitute the majority of customary harvests in the study area (M. Jones and A. Growcott, MPI, *personal communication*).

3.1 Commercial sector

Eight commercial crab fishers, out of a total of 22 registered, active fishers (36% response rate), agreed to be interviewed from the PAD1 fishery area. As this is the dominant crab fishing area in NZ and due to the paddle crab fishery being relatively small, the fishers interviewed comprised 25% of all active commercial paddle crab fishers in NZ. Three (14%) of the commercial fishers responded to email or phone contact but did not want to participate in the study.

Predominantly, these fishers did not wish to participate as they no longer fished for paddle crab or had not yet started fishing. Approximately half of the PAD1 fishers did not respond to email and/or phone contact. Low response levels may have introduced non-response bias in these results (whereby the answers given by participants might not adequately represent the full population of commercial crab fishers). The majority of fishers that were interviewed lived and fished out of Whangarei, although one interviewee was from the Bay of Plenty region.

3.1.1 Background information on the crab fishery

No distinct crab fishing season was apparent, with fishers commenting that they check their pots daily and year-round, weather dependent. There are no legal restrictions on gear and hence a range of pot designs are used. Many fishers

have modified commercial pot designs to increase efficiency as their knowledge of the species and fishery grew. The most innovative (yet simple) pot designs have escape holes situated throughout the pot to enable undersized crabs to exit. This is suggested to reduce the effort for the fishers in lifting, sorting and throwing back the undersized crabs. Crab pots remain in place in the water and are only brought into the harbour when stormy weather is forecast. Given the shallow water in which crab fishing takes place, only small boats are required.

Crab fishing is undertaken individually or with one other crewmember to assist with on-board activities. A size limit (CW per crab) is market driven and self-imposed by the fishers themselves. In particular, fishers noted that more meat is in larger crabs, which proves easier to extract. Larger crabs therefore gain a higher per kilo price on the market. Bycatch species include octopus (*Pinnoctopus cordiformis*) and whelks (*Cominella adspersa*) that are also landed and on-sold. Catch rates for paddle crabs are highly variable in both the short and long term as noted by a number of participants:

“They stopped biting last week for three days, couldn’t catch a crab. You’d almost think we’d caught them all, then bang, they’re back on”
(Commercial crab fisher)

“...I’ve seen them disappear for months, I don’t really know if they moved out to the deep, whether the boys doing it in the past couldn’t catch them, it’s a bit to do with swell and there’s all sorts.”
(Commercial crab fisher)

This has resulted in a fluctuating number of fishers targeting *O. catharus*. Fishers interviewed covered a range of experience in the fishery from half a year to 12 years (an average of 4.7 ± 1.2 years). Some fishers relied on crab fishing as their sole source of income, while others diversify by fishing other species as well (flounder, mullet etc.), or they run other businesses related to the industry such as processing operations and fish retail stores. The majority (75%) of commercial fishers said that a ‘decent living’ can be earned from crab fishing alone. Some of the fishers interviewed no longer fished for paddle crab though they were

actively fishing in the area after the arrival of *C. japonica*, hence these individuals were also interviewed to ascertain their perceptions on the impact to the fishery.

The price fishers receive for their catch varies predominantly due to size (as stated above), but many also stress the importance of building relationships with their customers and providing reliability in supply. A couple of the crab fishers are licensed fish receivers (LFRs), which enables them to sell their catch directly to restaurants and shopkeepers. The crab fishers that still actively fish said 30-40 hours a week was spent fishing.

3.1.2 Perceptions of change in the fishery

All commercial fishers interviewed discussed a significant reduction in the catch rate of *O. catharus* in the past. Whether this catch reduction occurred due to one major event, or if it was an outcome of a series of multiple catch reductions is inconclusive from these interviews. The majority (62%) of fishers suggested that a major reduction in catch occurred around 2008-2009 and that this was a sudden occurrence rather than a gradual decline in catch. Two of the fishers that had only started crab fishing recently and have only been involved for short periods in this fishery said that 2013 and 2014 were years when the catch rate had also reduced. The fishers suggested a range of reasons as to the cause of these fluctuations (Table 3). Fishers said the crab fishery has only recovered in the last 3 years (2014 onwards) from these declines, with many fishers now returning to crab fishing during this time and a number of younger new entrants getting involved in this sector for the first time.

The majority (75%) of fishers interviewed leased PAD quota, with only two fishers owning quota. The price of quota appears to have increased in recent years as well as the port prices fishers receive for their catch. Fishers felt that the port price increases were due to larger sized crabs being caught and taken to market, and building strong relationships with their buyers. In response to fluctuations in catch rate, fishers noted that they increased their effort, explored new locations, switched to fishing other species, or left the fishery altogether.

3.1.3 Knowledge and perceived impacts of *Charybdis japonica*

Of the eight commercial fishers interviewed, only two fishers said that they had caught *C. japonica* in crab pots before. Both noted that they had reported their catches to MPI at the time, as is required under the Biosecurity Act. One incident where *C. japonica* was caught occurred in Tauranga Harbour (between 2008-2009) where there is no reported establishment of *C. japonica* at this point in time. The second report of a *C. japonica* catch was in the surf zone in Bream Bay in 2010. Both catches involved 3-4 specimens being caught in pots. All other fishers interviewed had not caught *C. japonica* in pots but had witnessed personally, or heard that *C. japonica* are caught in set nets for flatfish within Whangarei Harbour and Kaipara Harbour on Northland's west coast (Table 4). Many of the fishers are aware of the relative aggressiveness of *C. japonica*, with some providing the following comments:

"These [C. japonica] are really ferocious man" (Commercial crab fisher)

"...They'll break the surface of the bucket trying to get at you. We've had them in the boat before and they'll come across the boat and have a go at you, they have no fear." (Commercial crab fisher)

"Our [native] crabs don't stand a chance against ones like that."
(Commercial crab fisher)

All fishers interviewed were of the opinion that, at the present time, *C. japonica* had not had an impact on the *O. catharus* fishery (Table 5). All fishers agreed that *C. japonica* could have a commercial value and potentially lead to a new fishery in NZ depending on factors such as there being a large enough population to fish commercially and the acceptance of an alternative product by the market. Two fishers suggested it could be one of the only viable management options for this introduced species. One fisher expressed concern over creating a market for *C. japonica*, as this could sustain its presence in NZ as opposed to eradicating it.

Table 3. Commercial fishers perceived reasons for the reductions in the catch rate of *Ovalipes catharus*.

Interview question	Responses
<i>What do you think has caused the reductions in paddle crab catch rates seen in the past?</i>	<p data-bbox="674 379 1989 443">"We did get a lot come up the beach... Right along the beach there was just tonnes and tonnes of crab washed up and we think that may have been a toxic algal bloom or something..."</p> <p data-bbox="674 488 2020 552">"Quite possibly the snapper I think. They'll destroy them. There's a lot of snapper that come into Bream Bay where the crabs are."</p> <p data-bbox="674 563 1827 587">"...My friend rang up and said, 'Hey, they are all dead on the beach as far as you can see'. They got a virus."</p> <p data-bbox="674 644 2020 780">"Whenever a storm would come sewerage pipes would overflow letting massive amounts of raw sewerage into the harbour. One particular weekend they let a million and a half litres of raw sewerage go down the harbour. They were having problems with the pumping station. Two weeks later all our crabs were dead. So, we wonder whether an algal bloom formed from all that waste and they ate it, who knows."</p> <p data-bbox="674 831 2002 895">"...I don't know if collapse is the right word for it, it just stopped. When it disappeared the fishing in Bream Bay wasn't very good either because the fish were eating the crabs. Fish started eating the pilchards, no pilchards, no crabs, no fish."</p> <p data-bbox="674 938 2020 1002">"...The catch rate of the crabs had just dropped and we don't know why...We assume it was this algae getting into the gut of the shellfish and the crab. The shellfish population was decimated, we assume it was this paralytic shellfish poisoning..."</p> <p data-bbox="674 1045 1973 1069">"We don't know if the paddle crabs up and packed their bags and walked away or whether we caught all the big ones..."</p> <p data-bbox="674 1126 2020 1227">"An environmental disaster, just nature, can't control the ocean. It all depends on who you talk to, how the crabs fell over to begin with, some people say it's the port, some people say it's the refinery, it could be that the snapper exploded and ate them all. You just don't know."</p>

Table 4. Instances of sighting *Charybdis japonica* by commercial fishers.

Interview question	Responses
<i>Have you ever noticed the non-native crab in your catch?</i>	<p>"Yep. Where we fish [for <i>O. catharus</i>] I haven't seen one but in our harbours I have. I don't know but from what I've seen they are around rocks and oyster bed areas, places like that with a lot of mud around. We just catch them when we are flounder fishing."</p> <p>"Not in Bream Bay but in Parua Bay [within Whangarei harbour]. I think they are more in the estuary, like in the harbours, more than they are in the open ocean."</p> <p>"Not in our crab catch at all but we've noticed it in our net fishing, in our flounder fishing. I know flounder fishermen right now that are literally getting plagued with them."</p> <p>"I have caught them on long lines in the Hauraki Gulf I'm pretty sure. It comes up clipped to tracers, biting onto them."</p> <p>"No not in with the paddle crabs but I caught some in my mullet net, we got some up in the mud flats up by Portland [within Whangarei harbour]."</p> <p>"Never caught them with the paddle crabs, only ever caught them where the paddle crabs haven't been you know? If they don't get along or whatever I don't know."</p> <p>"Yes, I have and reported it...They were right in the surf zone and I picked up about 4."</p> <p>"Yeah, I only caught them the once, I might have caught them before but didn't notice, these ones I did."</p>

Table 5. Commercial fishers perceived impact of *Charybdis japonica* on the *Ovalipes catharus* fishery.

Interview question	Responses
<i>Do you think the non-native crab has had an impact on the fishery?</i>	<p data-bbox="663 371 976 395">"Not yet, not that I know of."</p> <p data-bbox="663 445 1402 469">"Not in our fishery, not yet. We haven't seen any so...not even one."</p> <p data-bbox="663 518 1274 542">"Not at this stage, no. I think it is affecting other fishing."</p> <p data-bbox="663 592 1709 616">"...The crab fishery had declined dramatically before I started to catch that crab, the non-native."</p> <p data-bbox="663 665 1944 730">"I haven't seen it. He's meant to have been here since 2000 and our fishery has only just come back in the last...3 years so I would say [in regards] to our fishery, he hasn't done anything to it because it's back better than ever."</p> <p data-bbox="663 786 1223 810">" I don't really know, I haven't done it long enough."</p> <p data-bbox="663 860 1928 925">"No not yet but it will do...It will displace our native species long term if they get up enough numbers, it's such an aggressive crab. It's not [just] the threat they are putting on our crab, it's the native species they're going to feed on."</p> <p data-bbox="663 975 1951 1040">"I haven't seen it yet but when they talk about Waitematā Harbour being full of them...maybe there's a reason they are there and not on the coast, maybe they don't like the surf..."</p>

3.1.4 Commercial catch rate analysis

The annual average commercial paddle crab landings for the 27-year sampling period indicated that there were clear differences in catch rates across the five main QMAs (Figure 12), noting that quotas differ for each management area. The PAD1 management area has the largest quota of these five QMAs (Table 2; Figure 12). TACC for paddle crab was introduced in the 2002-2003 fishing season (two years after the *C. japonica* incursion) to help manage stocks and is a reflection of the available stocks in the region (i.e., larger TACCs represent a larger stock population). In general, all the PAD QMA landings, except for PAD7, remained below the TACC's (Figure 13). PAD7 exceeded their allocated TACC for the first seven years after the TACC was introduced, with catches declining to 0 tonnes in the 2015-2016 fishing year (Figure 13d).

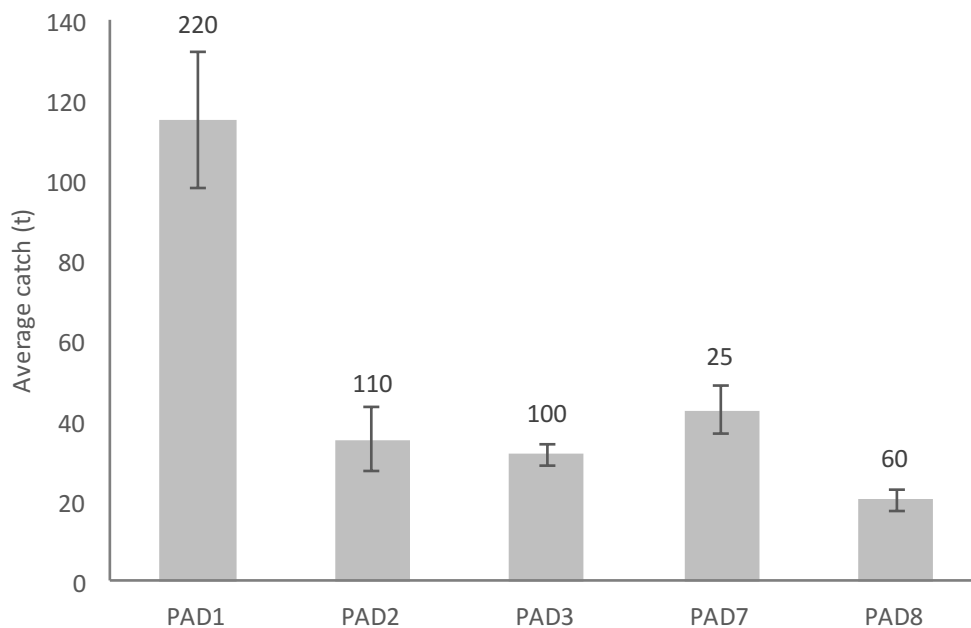


Figure 12. Average total catch rates for *Ovalipes catharus* from the 1989-1990 season to the 2015-2016 season (27 years). Errors bars are standard errors. Catch data is from MPI (<http://fs.fish.govt.nz/Page.aspx?pk=7&tk=100&sc=PAD>). Numbers at top of each column is the Total Allowable Commercial Catch (TACC) per QMA, which came into effect in the 2002-2003 fishing season.

There was a statistically significant difference between the total average catch rate in each of the five-main QMAs ($H_{[4]}=30.544$, $p < 0.001$). A *post-hoc* multiple comparison analysis (Tukey test) indicated that differences in catch occurred between four of the QMAs (Table 6; Figure 13). PAD1 had higher catch rates than other management areas, which is also reflected in the higher TACC set for this region. However, this analysis was not standardised for allowable catch. Thus, to take into account the changes in fishing behaviour that may have occurred after the introduction of the TACC, a two-tailed t-test (for parametric data) or a Mann-Whitney Rank Sum test (non-parametric data) were used to compare pre- and post-TACC catch rates for each of the QMAs individually. This further analysis showed a statistically significant difference between the pre- and post-TACC catches in PAD1, PAD7 and PAD8 (Table 7; Figure 13). In general, all of these QMAs have shown declines in catch after the TACC was introduced (Figure 13). Both PAD7 and PAD8 remain free of *C. japonica* and hence changes in the catch rates pre- and post- TACC are due to some other factor/s.

An analysis of catch rates for individual QMAs was also undertaken to examine pre- and post-*Charybdis* incursion effects. Again, both parametric and non-parametric tests were used to examine patterns in individual QMAs, with the results summarised in Table 8. PAD1, PAD7 and PAD8 all had catch rates that differed statistically before and after the *Charybdis* incursion. Of these sites, PAD1 was the only QMA where *C. japonica* is present, hence is the only QMA that is likely to have suffered impacts from this incursion. According to the commercial catch records, *C. japonica* induced impacts are unlikely given that other QMAs that were infection-free also exhibited significantly altered catch rates. Occam's razor would suggest that it is likely that some other unmeasured variable affected catch rates in the pre- and post-*Charybdis* period.

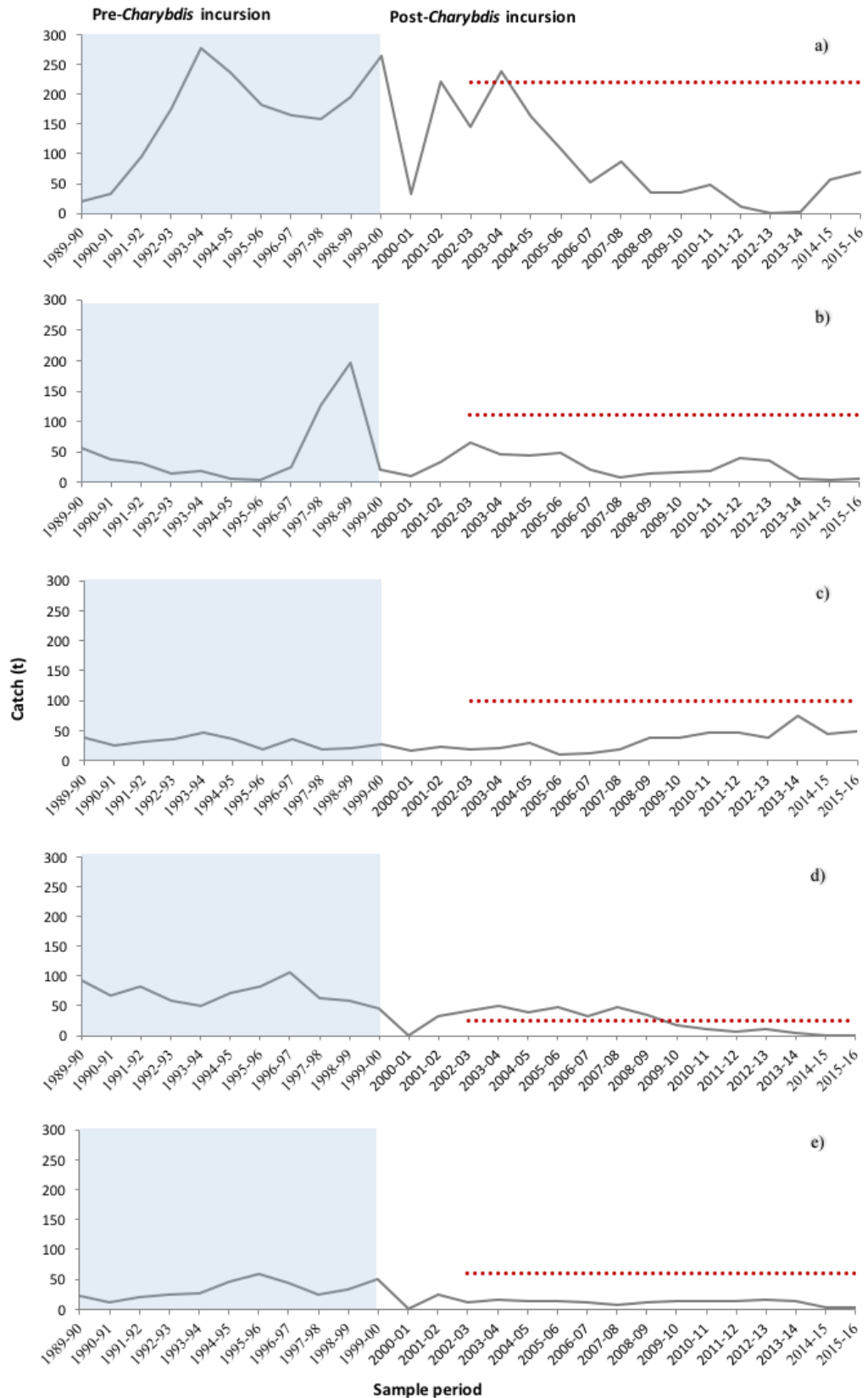


Figure 13. Reported paddle crab landings (t) in the five main QMAs: a) PAD 1; b) PAD 2; c) PAD 3; d) PAD 7; and e) PAD 8. Derived from MPI (2016) catch rate data. The red dotted line represents the TACC.

Table 6. All pairwise comparisons (Tukey test) to isolate differences in total catch rate between five paddle crab QMAs (PAD1, PAD2, PAD3, PAD7, and PAD8). Statistically significant differences are highlighted in bold font.

Comparison	Difference of ranks	q	p
PAD1 vs PAD8	1511.500	7.437	<0.001
PAD1 vs PAD2	1129.000	5.555	<0.001
PAD1 vs PAD3	905.500	4.455	0.014
PAD1 vs PAD7	706.500	3.476	0.100
PAD7 vs PAD8	805.000	3.961	0.041
PAD7 vs PAD2	422.500	2.079	0.582
PAD7 vs PAD3	199.000	0.979	0.958
PAD3 vs PAD8	606.000	2.982	0.216
PAD3 vs PAD2	223.500	1.100	0.937
PAD2 vs PAD8	382.500	1.882	0.672

Table 7. Two-tailed t-test comparing individual quota management areas with pre- and post-TACC paddle crab catches. Where t = t-test and U = Mann-Whitney Rank Sum test.

QMA	Statistic	Degrees of Freedom	P value
PAD1	t = 2.756	25	0.0108
PAD2	U = 82.500	1	0.698
PAD3	t = -1.097	25	0.283
PAD7	t = 4.180	25	0.000312
PAD8	U = 22.000	1	<0.001

Table 8. Two-tailed t-test comparing individual quota management areas with pre- and post-*Charybdis* incursion paddle crab catches. Where t = t-test and U = Mann-Whitney Rank Sum test.

QMA	Statistic	Degrees of Freedom	P value
PAD1	t = 2.141	25	0.0422
PAD2	U = 84.500	1	0.807
PAD3	U = 72.000	1	0.392
PAD7	t = 4.509	25	0.000133
PAD8	U = 26.500	1	0.002

3.2 Recreational sector

Thirty five (out of 55) recreational fishers agreed to participate in the survey, a 64% response rate. People seen to be setting and retrieving crab pots during the sampling period were considered to be recreational crab fishers and it was those individuals that were approached to participate in the survey.

3.2.1 Recreational fishers perception of the fishery

None of the recreational fishers surveyed lived locally in the Bream Bay region. Recreational fishers stated that they had travelled for 2-3 hours to reach the fishing location. Bream Bay was the most common location participants fished for crab (81%). Other locations participants had fished for crab were Whangarei heads, Omaha, Whitianga (all located in the north east of the North Island) and Christchurch (east coast of the South Island). Most survey participants (63%) said that they enjoyed fishing as a recreational activity. Close to half (45%) of participants fished with friends, with 38% fishing with family members. A small proportion fished with extended family or by themselves (8% respectively). 63% say that they had or would teach a younger family member how to fish for paddle crab.

Almost one-third of surveyed fishers (31%) had only ever fished for crab. It was more common (53%) for participants to have fished for a range of species (e.g., snapper, kahawai, herring, kingfish). A small proportion (15%) also harvested shellfish occasionally (e.g., cockles, oysters, mussels). Most fishers said paddle crab was not an important food source to themselves and/or their immediate family, their extended family or friends (Figure 14). One fisher said paddle crab was a luxury item for them, others commented that they fished for fun and that it provided a chance to have a day at the beach.

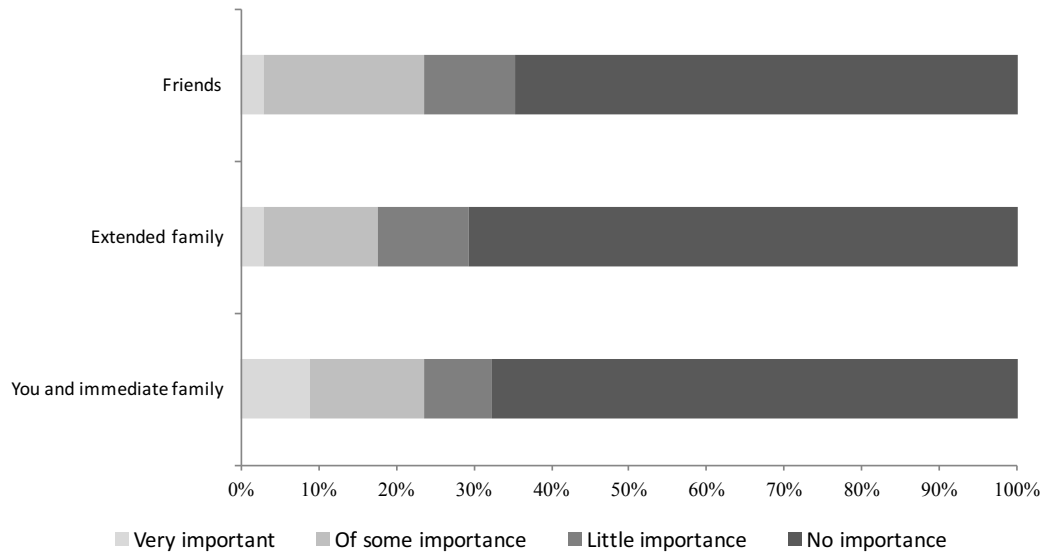


Figure 14. Recreational fishers self-reported perceptions of the importance of paddle crab as a food source to themselves and their wider networks.

A set of general questions (based on a larger analysis that is currently occurring in NZ; Campbell and Hewitt, unpublished data) were asked of the participants to help identify how they perceived certain coastal values related to the health of NZ coastal regions. These questions examined the importance of safe water; clean water; and biodiversity. The two values that are linked to personal benefit (water safety and cleanliness) were rated higher than biodiversity, yet all values were considered to be important (Figure 15).

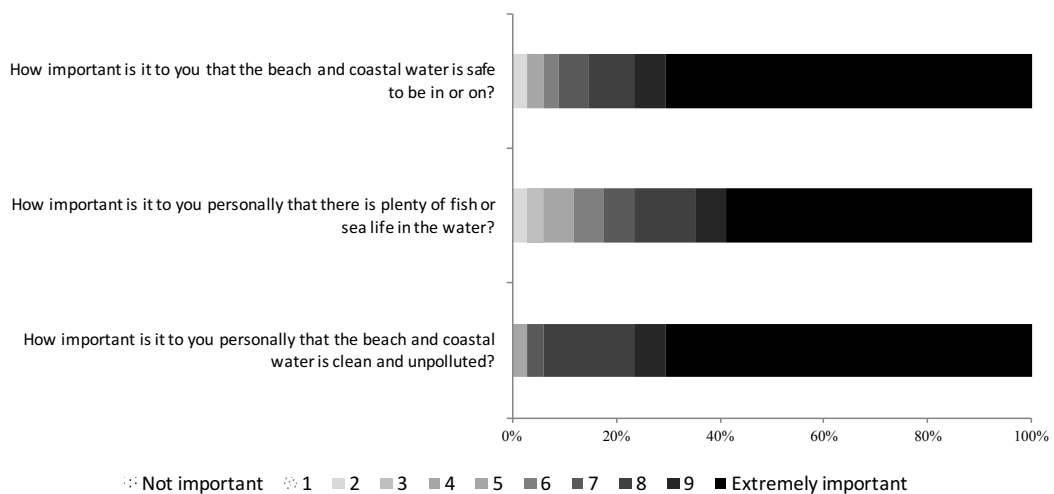


Figure 15. Recreational fishers self-reported perception of the importance of wider coastal values relevant to the recreational paddle crab fishery.

Participants had been fishers (of any species) an average of 6 years (± 2 years). Though for paddle crab specifically, the majority of participants (88%) said they had only started fishing for crab in the past year (Figure 16). The majority (70%) of participants said they knew others that also fished for paddle crab (an average of four other people). Two widely available crab pot types were used by fishers- the collapsible pot and the 'opera house pot'. Information on the type of bait used was not collected, but field observations suggest that the common baits were chicken carcasses and jack mackerel fish (Weaver, *personal observation*). All fishers set the crab pots by manually deploying the pots into the surf zone. This is done by wading out to where the water depth reaches waist/chest height and positioning the pot on the seafloor. A buoy or other floatable marker is attached to the pot and used to mark the pots position for retrieval.

The majority of fishers (97%) said that they eat the crabs they catch, though one participant stated they would be returning them to the sea at the end of the day, explaining that they were predominantly fishing for fun. Sixty-two percent of participants stated that there were certain times of year that they fished for paddle crab (November-February), with the remainder of the participants stating that they fished at any point in the year (opportunistic fishers).

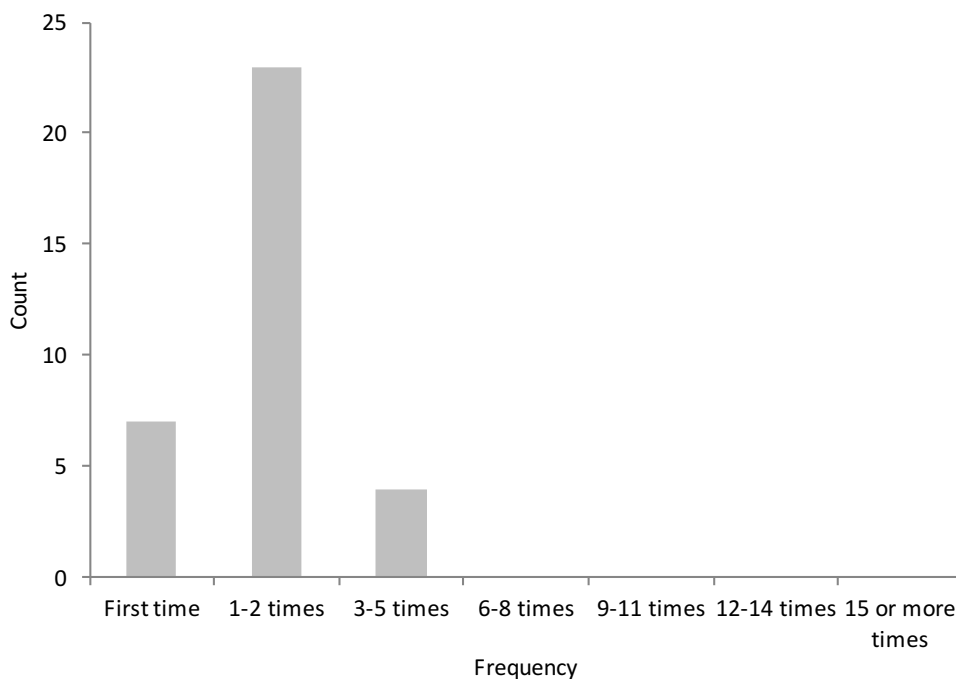


Figure 16. How often recreational fishers fished for paddle crab in the past 12 months.

3.2.2 Perceived changes in the *Ovalipes catharus* fishery

With the majority of fishers having only fished 1-2 times in the past year (Figure 16), the ability to elucidate patterns of change within the fishery from the perspective of recreational users was very limited. Close to half (51%) of the participants were unsure if any changes in paddle crab catch rates had occurred. Just over a quarter (27%) of recreational fishers had not noticed any changes in the amount of crabs they caught, with a fifth (21%) of the participants feeling that changes had occurred (51% unsure due to limited experience in the fishery). Of the participants that felt that changes had occurred in their paddle crab catch rates, the majority (86%) said catch rates had reduced, with only one individual saying their catch rate had increased over time.

3.2.3 Knowledge and perceived impacts of *Charybdis japonica*

Two-thirds (65%) of fishers surveyed were unaware of non-native crabs arriving and establishing in NZ. Just over a third (35%) were aware of non-native crabs in NZ. Participants level of self-stated concern regarding non-native crabs appearing in NZ elicited a range of responses (Figure 17). Thirty-five percent of recreational fishers stated that they had heard of *C. japonica* before taking part in the survey. Participants information sources included the media as well as seeing it/eating it in it's native range. Some participants had heard that *C. japonica* is competitive or stronger than *O. catharus* and that *C. japonica* is an efficient consumer of shellfish. The vast majority (91%) of recreational fishers stated that they had never caught *C. japonica* in NZ, with 9% of participants stating that they were unsure as to whether they had caught *C. japonica* in NZ. A high proportion (80%) of recreational crab fishers stated that they would eat *C. japonica* if they caught it.

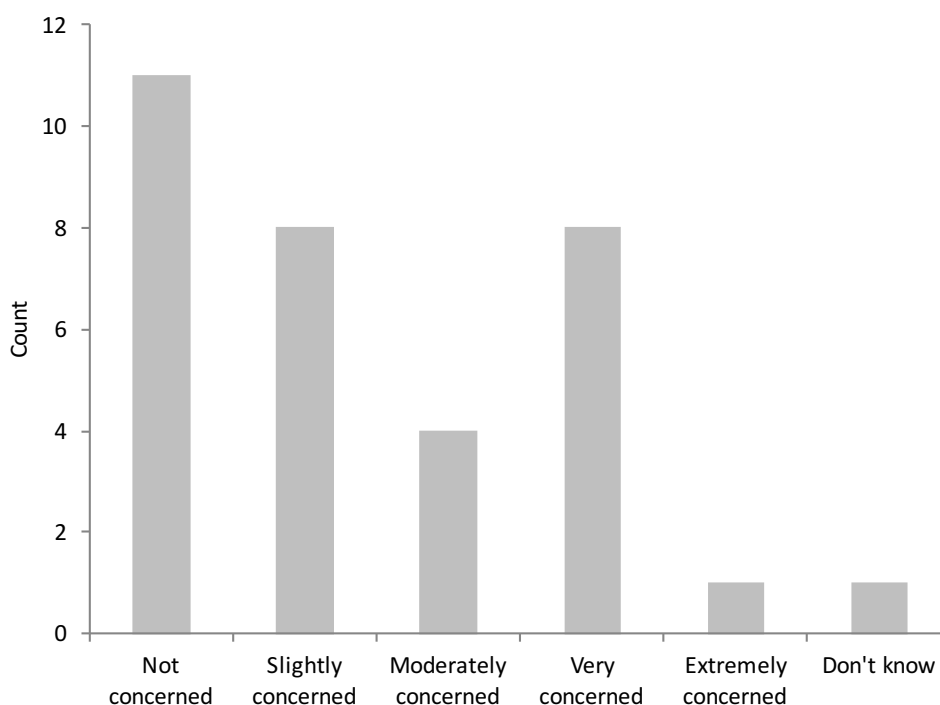


Figure 17. Recreational fishers self-declared concern over non-native crabs in New Zealand's coastal waters.

When fishers were asked to judge if they believed that *C. japonica* could be harmful or of benefit to NZ, many were unsure (Figure 18). Their basis for uncertainty was due to a self-reported lack of knowledge of the species (Figure 18). Other opinions put forward by the participants included:

- that a negative impact was not yet proven;
- that *C. japonica* will spread easily due to its competitive nature hence it will have a negative impact; and
- that non-native animals are always a problem.

When asked who participants felt should be responsible for managing the non-native crab throughout NZ's coastal areas, the majority (54%) felt that the 'Government' held full responsibility, followed closely by regional and local councils, then all New Zealanders, businesses that operate in the local area and lastly, fishers and visitors to NZ's coastal regions (12%; Figure 19). In general, recreational fishers felt that they were the group least responsible to manage this issue (Figure 19).

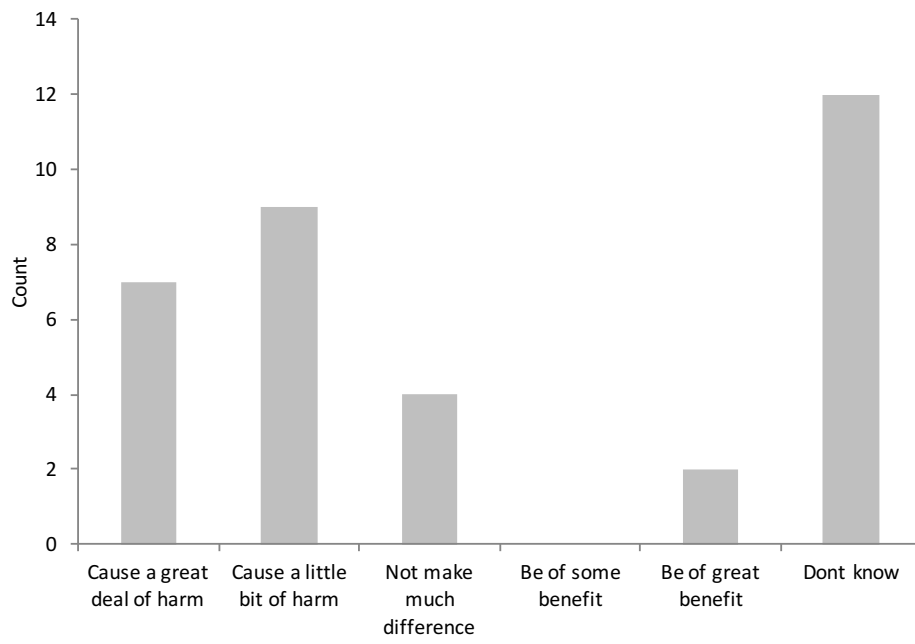


Figure 18. Recreational fishers perception of impact that *Charybdis japonica* could have in New Zealand.

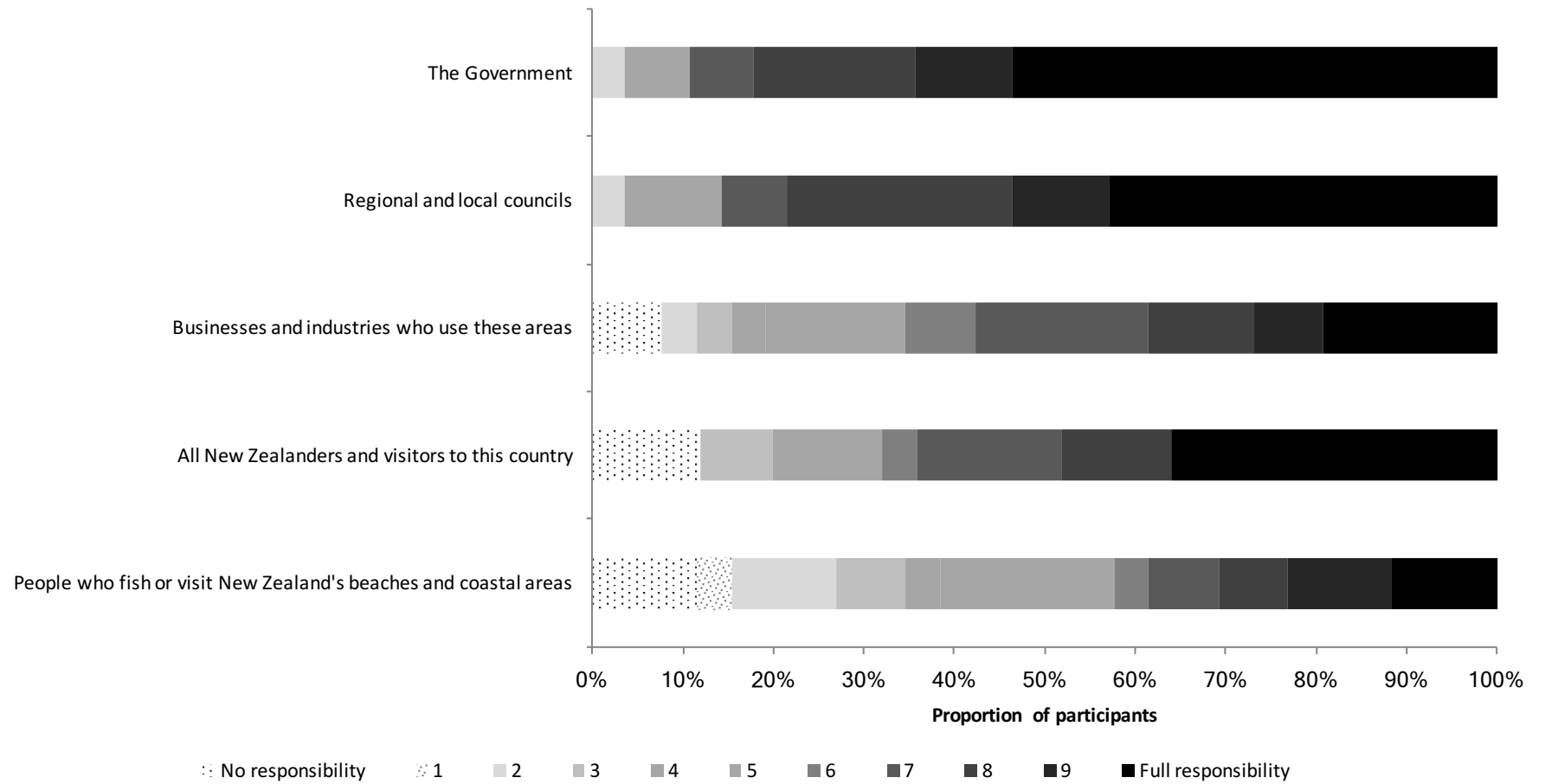


Figure 19. Who recreational fishers feel has the responsibility of managing *Charybdis japonica* in New Zealand.

3.3 Accuracy of species identification across sectors

Thirty-seven of the 43 sampled participants (8 commercial and 29 recreational fishers; response rate of 86%) opted to attempt to identify *O. catharus* from a series of four crab images (Appendix E). All commercial fishers identified *O. catharus* accurately (100%), with a high majority (93%) of recreational fishers also identifying *O. catharus* accurately (Figure 20). There was no statistically significant association between the type of fisher and their ability to accurately identify *O. catharus* ($p= 0.99$, Fisher's exact test).

Following on from this, 36 of the of the 43 sampled participants (8 commercial and 28 recreational fishers; 84% response rate) across both fishing sectors opted to attempt to identify *C. japonica* from a series of four crab images. A higher proportion (75%) of commercial fishers identified *C. japonica* accurately relative to recreational fishers (50% accuracy) from the images they were shown (Figure 20). There was no statistically significant association between the type of fisher and their ability to identify *C. japonica* ($p= 0.26$, Fisher's exact test). Overall, close to half of participants across both sectors identified *C. japonica* correctly (55% of participants). A higher overall accuracy in identification was observed for *O. catharus* (95% of participants accurately identified *O. catharus*).

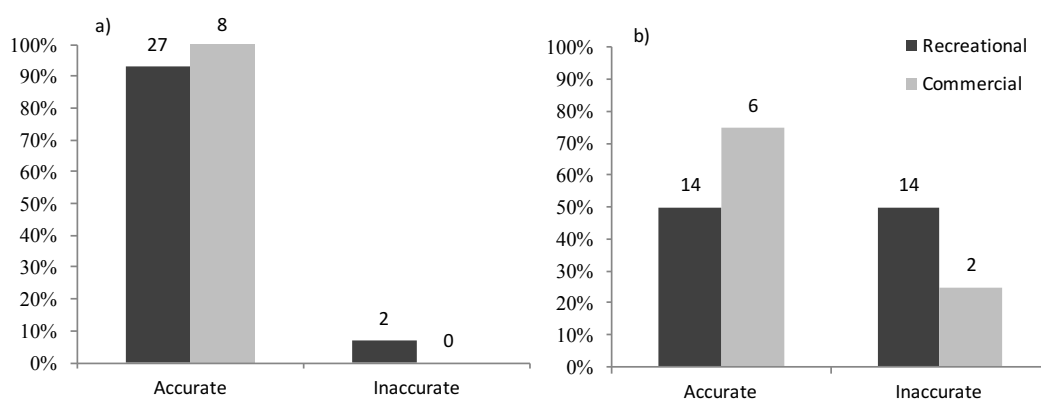


Figure 20. Accuracy of fishers (both recreational and commercial) ability to identify: a) *Ovalipes catharus*; and b) *Charybdis japonica*. The numbers at the top of each column show the actual numbers of participants in each group.

4. Discussion

This study investigated the knowledge and perceptions of fishers across recreational and commercial sectors in combination with catch data records to ascertain if *C. japonica* has impacted upon *O. catharus* populations. It was anticipated that observable impact from *C. japonica* may be evident via changes in the paddle crab fishery within the invaded region. The knowledge of crab fishers may prove useful in informing how the *C. japonica* incursion can be better managed from a biosecurity context. Fishers have a wealth of knowledge that can be drawn upon (Haggan et al., 2007), based upon their long-term exposure to the population dynamics of both *O. catharus* and *C. japonica* in northern NZ (Fowler 2011). Crab fishers observe crab population fluctuations on a daily basis over many years. These observations can provide a depth of informal knowledge and understanding that could not be obtained from quantitative research alone (Fowler 2011). Within this study, three hypotheses were explored:

- Has the incursion of *C. japonica* in NZ resulted in a significant decline in *O. catharus* catch rates;
- Have fishers perceived a change in the paddle crab fishery since the arrival of *C. japonica*; and
- Can fishers accurately identify *O. catharus* and *C. japonica*.

4.1 Has catch rate been affected?

The largest abrupt shift in the PAD1 fishery appears to have occurred in the 2000-2001 fishing year when the catch rate dropped by 233 tonnes from the previous year. The majority of this loss (189 t) was recouped the following fishing year (2001). Although 2000 is also when *C. japonica* was first detected in NZ, it is unlikely to have caused the sharp reduction in the catch rate of *O. catharus* in the same year. Introduced species can have immediate impacts however, a time lag between the initial invasion and population/ range expansion is common (Jeschke et al., 2014). Lag periods can extend over years or even decades (Crooks and Soule, 1999) and impacts have the potential to increase as introduced species establish and spread (Jeschke et al., 2014). The founding population of *C. japonica* is thought to have consisted of approximately three specimens (Wong et al., 2016). Such a small population may have been vulnerable to stochastic environmental conditions (Lockwood et al., 2005), whereby time is required to locally adapt and establish (Crandall et al., 2000; Lee, 2002). The population dynamics of an introduced species are known to fluctuate over time and space (often referred to as boom and bust cycles; Simberloff and Gibbons, 2004), as will species abundances in the invaded habitat in response to the new arrival (Parker et al., 1999). Therefore, it is unlikely that *C. japonica* impacted upon the *O. catharus* fishery and caused the abrupt catch shift that is recorded.

Furthermore, *C. japonica* was first detected in September 2000 and the commercial fishing year in which this large reduction occurred commenced 1st October 2000 and ran till 30th September 2001. PAD1 covers the entire coastal area of north east New Zealand, whereas *C. japonica* was only established in a relatively small region (one harbour) of this area at that point in time. Large catch rate reductions in the 2000-2001 fishing year were also evident in PAD7 and PAD8, both located along the lower west coast of NZ, areas well outside the known invaded range of *C. japonica*. The high overall variability in landings across the whole fishery are considered to be a reflection of market variations (Stevens et al., 2000; MPI, 2016). It is likely that other factors are influencing the

variability in the *O. catharus* population:

“Fluctuations in abundance and recruitment are characteristic of several commercially exploited crab populations and may be the result of fishing or the consequence of a vast array of interacting environmental and biotic factors intrinsic to the marine ecosystem”
(Jamieson, 1986 in Osborne, 1987).

Indeed, the original population increase of *O. catharus* that instigated the fishery in the 1980's was purported to be due to a combination of 'favourable hydrological conditions' (sea currents and temperatures) and overfishing of predatory fishes (Wear, 1982; Osborne, 1987; Stevens, 1999). Early in the development of the paddle crab fishery, Osborne (1987) highlighted that the unpredictable recruitment and subsequent stock density fluctuations could lead to future sustainability problems. The high temporal and spatial variability in commercial landings make it difficult to elicit any clear patterns of decline in the *O. catharus* fishery that could be a result of a range of factors (for example, changes in fishing technology, change in the number of fishers or change in environmental factors).

Commercial catch data is used in this study as a crude measure of the large-scale abundance of *O. catharus* though it is important to highlight that changes in abundance are just one way populations may respond to an invader. Native populations may also alter their distribution, age/size structure or growth rates (Parker et al., 1999). The background fluctuations in populations (e.g., natural variation caused by environmental factors) further complicate the ability to elucidate clear measurable responses by native species to invaders (Parker et al., 1999). Impacts from an introduced species can vary across both space and time, leading to uncertainty in the ability to conduct a static risk assessment of a fluctuating issue occurring within an equally fluctuating environment (Mach et al., 2013).

Therefore, the hypothesis tested here (if the incursion of *C. japonica* in NZ has resulted in a significant decline in *O. catharus* catch rates) is unsupported by the results in this thesis and the data available from catch rates. The catch rate of *O. catharus* dropped when *C. japonica* was first detected but this was coincidental and for reasons discussed above, it is highly unlikely that this reduced catch was due to the invasion of *C. japonica*.

4.2 Do fishers perceive a change in the paddle crab fishery due to the *Charybdis japonica* incursion?

Commercial crab fishers had perceived changes in the fishery though these were not considered to be because of *C. japonica*. Recreational crab fishers had a limited experience of the fishery so were unable to provide much insight into perceived changes in the crab fishery. Thus, the hypothesis of a perceived change in the fishery due to *C. japonica* cannot be supported.

Many of the commercial fishers interviewed felt that there had been a substantial decline in the catch rate of *O. catharus* in 2008-2009. This was perceived to be the largest change in catch rates during their respective times involved in the fishery. Comparing the perceived decline to the reported catch rates within PAD1 show there had been a reduction of 50 tonnes from the previous fishing year. Though this is not a negligible reduction, it is only a small shift in comparison to the fluctuations that have occurred across the entire fishing history in PAD1. The commercial fishers interviewed have been involved in the paddle crab fishery for a maximum of 12 years (median 3.5 years), so have not experienced the larger fluctuations evident in the catch history data. It is highly likely that the perceived catch rate changes of the fishers were notable within the time-period they have/had been actively fishing.

It is evident that *C. japonica* has increased in abundance in harbours and estuaries throughout northern NZ over the past 17 years (MPI, unpublished data). Despite this, its occurrence in sandy, coastal systems commonly inhabited by *O. catharus* (and where the paddle crab fishery predominantly occurs) is perceived to be minimal by fishers. This is further substantiated in the delimitation surveys by Gust and Inglis (2006), which suggests *C. japonica* favours muddy sediments. In response to the cause behind catch rate reductions of *O. catharus*, commercial fishers provided a range of suggestions that would require further investigation as to their validity or perceived link to catch declines. The short-term experience of the majority of recreational fishers surveyed made any

perceptions of change within this sector of fishery difficult to ascertain. Though recreational crab fishers would not likely be fishing at the same frequency as commercial fishers, more long-term perceptions of change from this sector (i.e., via a longitudinal study) would be beneficial in providing a comparison to commercial perceptions.

All of the commercial fishers and 35% of recreational fishers had some knowledge of *C. japonica* prior to taking part in this study. Recreational fishers were, for the most part, unconcerned over introduced crabs in NZ (Figure 17) and were mostly unsure of the impact *C. japonica* could have in NZ (Figure 18). Commercial fishers were more dubious of the impact *C. japonica* could have, giving the dominant opinion that impacts were 'not yet' evident (Table 5). The perception that recreational fishers felt the least responsible for managing the introduced crab (Figure 19) infers that there may be a disconnect between fishers actions and their potential to be a secondary dispersal vector. This outcome suggests that there may be challenges when engaging with this group to improve biosecurity messages and outcomes.

4.3 Can fishers accurately identify the native and introduced crabs?

Both sectors showed a lower accuracy in identifying *C. japonica* relative to *O. catharus* (95% of participants identified *O. catharus* correctly). Overall, around half (55%) of all (commercial and recreational) participants accurately identified *C. japonica*. Thus, the hypothesis tested here is refuted – in general fishers cannot accurately identify *C. japonica* to a high degree. All recreational fishers were actively fishing at the time of surveying though a small amount of participants (7%) still inaccurately identified *O. catharus*. The potential for misidentification of morphologically similar species is an aspect warranting consideration (Nuñez et al., 2012; Guiasu, 2016; Campbell et al., 2017), particularly if any public participation in the control of *C. japonica* was to occur in NZ.

The lack of a statistically significant difference in the identification accuracy of *C. japonica* across both recreational and commercial fishers may suggest that any public awareness campaign would have to target both sectors. However, this comment is made with caution, based upon the low sample sizes in the survey population. With all commercial fishers self-declaring their awareness of *C. japonica* (many having seen it personally) and 35% of the recreational fishers having heard of it, media sources have provided a substantial amount of information to the public already. The low accuracy in identification of *C. japonica* by recreational fishers further reflects the low overall knowledge of the introduced crab, as self-declared by these participants.

Though citizen science does receive some criticism over its scientific integrity (e.g., Conrad and Hilchey, 2011), within a biosecurity context, if sufficient identification information is provided, identification of species of concern by individuals exposed to environments at risk may be a valuable resource (Barker, 2000). A public campaign in 2010 targeted early incursions of *C. japonica* in Western Australia (WA) and the details provided subsequently resulted in recreational fishers being able to positively identify and report further incursions in 2012 (see Hourston et al., 2015). The public awareness campaign used in the

WA campaign effectively increased the search effort for the introduced species. This coupled with the quick action in managing *C. japonica* subsequently limited the ability for *C. japonica* to establish in WA and reach the densities and range currently seen in NZ.

New Zealand is fortunate in having a population that believes it is aware of the impacts of introduced species, both on land and in water (Hewitt et al., 2004b; Goldson et al., 2015). This has resulted in motivated communities concerned over changes to the many environments unique to NZ, as well as the endemic biodiversity residing within them (Royal Society of New Zealand, 2014; Goldson et al., 2015). Goldson et al. (2015) specifically highlights the many opportunities available to enhance citizen involvement in NZ, particularly for biosecurity surveillance. Though the densities reached by *C. japonica* in invaded locations may be beyond the benefit of public awareness campaigns, these could prove beneficial in limiting further spread (e.g., secondary spread) throughout NZ whilst incursions may only be small, and hence more manageable.

4.4 Valuing the paddle crab fishery

The total value of NZ marine ecosystems has been estimated at NZ\$184 billion per year, inclusive of fisheries (Patterson and Cole, 1999). Yet, this estimation is now somewhat outdated. The socio-economic importance of recreational fishing in NZ is demonstrated by:

- Fishing being the 5th most popular recreational activity of NZ;
- Annual spending by NZ recreational fishers is estimated at NZ\$857,218,094 (NZ's GDP in 2016 was \$185 billion); and
- Total expenditure of resident and visiting marine recreational fishers in the upper North Island of represents 77% of the annual spending (NZ\$663,280,150 per annum; Holdsworth et al., 2016).

Noting that these figures have been somewhat debated in the literature (see Crampton, 2017). Crab fishing is an attractive recreational fishery as it is shore based (boats are not necessarily required) and utilises a small amount of simple fishing gear. It attracts a range of people from different ethnic backgrounds and ages (Weaver, *personal observation*). It is commonly a group activity, perhaps lacking the exclusivity and more solitary nature of some recreational fisheries (such as surfcasting or kayak fishing). All recreational crab fishers that participated in this study had travelled approximately four hours (inclusive of return time) to reach Bream Bay, where surveys were undertaken. Spurgeon (1999) highlights that travel cost is a factor that requires consideration in the terms of the total recreational value of an activity. The value of *O. catharus* as a recreational food source appears to be minimal, although the experiential activity of fishing appears to have considerable importance to those interviewed.

Portunids are well known for demonstrating aggressive behaviour both intra- and interspecifically (Huntingford et al., 1995). This behaviour has been particularly instrumental in the success of several introduced crab species, with introduced crabs having restricted the populations of native crabs in some instances (McDonald et al., 2001; Jensen et al., 2002; Williams et al., 2006). Not

only is the aggressive nature demonstrated by *C. japonica* of concern to *O. catharus*, it may also impact on societal values by deterring recreational crab fishers from participating in this activity for fear of injury. It could also restrict other recreational activities such as swimming and wading in estuaries and harbours. Levin and Crooks (2011) provide examples of other introduced species that have had recreational impacts on swimmers elsewhere in the world, ultimately impacting tourism- a significant contributor to NZ's economy (a total tourism expenditure of NZ\$34.7 billion in the year ended March 2016).

Van Schooten et al. (2003) suggests that changes only become impacts when they become 'socially significant' (i.e., when something that people value is affected). The human dimension to values assists in determining the cost of damages in relation to introduced species, in turn, assisting in determining the level of investment appropriate in the form of management responses (Hamlin and Lodge, 2006). With commercial fishers of *O. catharus* suggesting the fishery is in a good condition and with large numbers of recreational fishers traveling to Bream Bay, no apparent impact from *C. japonica* has been perceived thus far. There is the potential that shifting baselines have skewed perceptions given the predominantly short temporal experiences in both the commercial and recreational sectors- a common issue in fisheries management (Pauly, 1995).

A number of researchers (McNeely 2001; Veitch and Clout, 2001; Shüttler et al., 2011) highlight how there is no single perception of introduced species by society, rather different opinions are held by different stakeholder groups. García-Llorente et al. (2008) elaborates on this further by showing that perceptions can also change over time. For example, in their study, only the most recent introduced species were recognised as such, with the distinction between native and non-native becoming blurred over time. The participants in this study were individuals with a considerable vested interest in the paddle crab fishery. Thus, their self-declared values and perceptions might not be reflected across other public groups. Similarly, the sample size for this study was small and did not reflect a representative sample of either the commercial or recreational

fishers. It is possible that current viewpoints on the impacts elicited by *C. japonica* could shift over time (or with a larger, more representative sample). There is even the potential for an introduced species to become valued over time (discussed further below).

4.5 Management considerations

Many of the recreational fishers surveyed stated that they would eat *C. japonica* if caught. Commercial fishers also commented that there could be a market for *C. japonica*. One commercial fisher does sell *C. japonica* at a local farmer's market when he catches it (the fisher does not specifically target the species, rather it is caught as bycatch in set nets). Given *C. japonica* is fished and consumed throughout its native range, doing so in its introduced range may be a viable option. In a commercial context, fishers do not believe the introduced population is of high enough density to sustain a commercial fishery at this point in time (though this could become a more viable fishery in the future).

One of the younger commercial fishers expressed concern over creating a market for the introduced species. There are indeed both positive and negative aspects to the creation of a market being employed as a management tool for introduced species. Hänfling (2011) suggests:

“Harvesting edible crustaceans for consumption and sale can be a productive alternative strategy under the philosophy of “making the best of a bad situation”” (Gherardi et al. 2011 in Hänfling, 2011).”

Hänfling and others (such as Nuñez et al., 2012 and Shüttler et al., 2011) add caution to this statement by highlighting how the application of commercial value to an introduced species often leads to further introductions. Furthermore, Simberloff and 141 colleagues (2011) have clearly objected to the concept of benefits from introduced species. The issue with creating an introduced species fishery is that an incentive is created to continue and potentially grow the industry. This is the very antithesis to the original 'fishing down' management option (aptly termed 'gastronomic control'; Nuñez et al. (2012).

Shüttler et al. (2011) considers the creation of a market an unsuccessful strategy due to this contradictory nature, whereby a successful market would undoubtedly try to maintain product supply. As an example, the blue swimming

crab, *Portunus pelagicus*, introduced to the Mediterranean via the Suez Canal has become a valued fishery, adding an aspect of desirability to further population expansion of this species (Hänfling et al., 2011). Thus, adding commercial value may actually provide some protection to an introduced species within newly invaded environments (Hänfling et al., 2011; Nuñez et al., 2012). Nuñez et al. (2012) further elaborates on the benefits and disadvantages of consuming invasive species;

Benefits:

- Increases public awareness of invasive species;
- Assistance in the detection and response mechanisms; and
- Boost to local economies (i.e., culinary or hunting value).

Disadvantages:

- No discernible reduction in the introduced species population;
- Creation of a market that may lead to maintaining the introduced species population; and
- Economic value eventually translates into social and cultural values that further complicate any management efforts.

Tooman (2008) suggests that the aggressive behaviour of *C. japonica* may act as a deterrent to people surreptitiously spreading the introduced crab into uninvaded areas. Given the territoriality of *C. japonica*, commercial fishers may face difficulties in low catch per pot quantities as was reflected in the MHRSSP surveys (MPI, unpublished data) and research by Gust and Inglis, (2006). As such, this would render the species too costly to catch on a commercial scale. Despite this, participants in this study appear to be open minded to the potential socio-economic benefits *C. japonica* could bring them. In time the potential benefits may become another factor to weigh against any negative impacts caused by *C. japonica*.

4.6 Further research

Given that the arrival of *C. japonica* into NZ waters is the first known, successful introduction of this species outside of its native range, the impact this species could have requires ongoing research. Within this study, small sample sizes limit the ability of the results to genuinely represent the commercial and recreational crab fishing sectors. Given the relatively small size of the crab fishery, all commercial fishers in the PAD1 area would need to participate to adequately represent the population. Calculating a representative sample of recreational crab fishers is a further challenge given the unknown population (no data is available on crab fisher numbers or recreational catch rates). A sample of the population in the study area would not be accurate given that anecdotal information and this study shows crab fishers are not from the local area. Any future research needs to invest more heavily in obtaining representative samples from each sector (and to include customary fishers). Ascertaining the cultural importance of *O. catharus* is important in any further investigation of the potential cultural impacts *C. japonica* may have.

How the arrival of *C. japonica* has affected the location and movement of *O. catharus* warrants further research. In terms of the direct impacts *C. japonica* may have on *O. catharus*, the dominant time this would occur would be when populations interact spatially (when *O. catharus* enters estuarine environments during the reproductive season). Given the comparatively docile behaviour of *O. catharus*, it may be that the native species is actively avoiding interspecific competition with *C. japonica* (Fowler, 2011). Indeed, there exists doubt that these two species will interact in the field to any significant degree (Gust and Inglis, 2006; Browne and Jones, 2006). Though competition can occur between adults of native and introduced species, and even juveniles, the overall impact this has on a native species may be masked by continued larval input from unaffected regions (e.g., open populations where progeny production and supply are spatially decoupled), effectively replenishing dwindling populations (Byers, 2009). This is a possibility to be considered in this case given the offshore

spawning and widespread larvae dispersal known of *O. catharus*.

Investigating the impact *C. japonica* has on *O. catharus* is but one interaction amongst many that could have occurred after the incursion, or that may occur into the future. As was also emphasised by Fowler (2011), further research is needed on the impact *C. japonica* could have on shellfish species and estuarine ecosystems. Concern is expressed over the impact *C. japonica* may have on estuarine bivalve species of both commercial and recreational importance, namely, cockles (*Austrovenus stutchburyi*), scallops (*Pecten novaezelandiae*), pipi (*Paphies australis*) and mussels (*Perna canaliculus*); Gould, 2004; Gust and Inglis, 2006; Fowler, 2011). Indeed, the impact to shellfish could potentially be substantial given the relatively sessile nature of bivalves. The impact *C. japonica* may pose to *P. canaliculus* is of notable concern given the importance of the green-lipped mussel to the NZ aquaculture industry and given that all mussel spat for the industry is sourced from Northland (this is predominantly sourced from Ninety-mile Beach located at the north-western tip of the North Island of NZ, an area currently uninvaded by *C. japonica*).

The commercial paddle crab fishers in this study also highlighted the impact *C. japonica* may be having on the flatfish fishery given the overlapping habitats in harbours and estuarine environments (the NZ flatfish fishery consists of eight species). *Charybdis japonica* is known to consume fish (Jiang et al., 1998) and has specifically been reported to consume juvenile flounder in Japan (Sudo et al., 2008). A similar study to the one conducted in this thesis, whereby both commercial and recreational flatfish fishers are interviewed alongside quantitative analysis of commercial landings may provide insight into the impact on this valuable commercial and recreational fishery.

The introduction of high densities of a permanent, estuarine dwelling crab will likely exert substantial top-down pressure across many trophic levels in invaded areas, as is evident in other estuarine crab introductions (Grosholz et al., 2000; Kraemer et al., 2007). The socio-economic impacts derived from these ecological shifts are not fully realised at this point. Though it may be uncommon for an

introduced species to drive a native species to extinction (Levin and Crooks, 2001), in terms of the impact on a fishery, the population must only be reduced below economic sustainability/ financial viability (Walton et al., 2002). Native species do have the ability to adapt to changes, such as to the introduction of a new species (Strauss et al., 2006). Adaption is also a common response to introduced species by society, a relatively passive approach in comparison to the significant task of eradication (Lodge et al., 2009).

4.7 Conclusions

This study provides a comprehensive insight into the paddle crab fishery in NZ. Due to the multi-faceted, varying impacts from an introduced species, there is considerable opportunity to misrepresent the socio-economic costs derived from *C. japonica*. Impacts from introduced species are ultimately context-dependent and vary across time and space. To suggest that any fluctuations in *O. catharus* commercial and recreational catch rates are specifically due to the arrival, increase in abundance and range expansion of *C. japonica* cannot be ascertained in this study. Market-led catch variability in the paddle crab fishery and a multitude of unmeasured factors could be at play in the true population dynamics of *O. catharus*. It could be suggested from the perceived impacts demonstrated in this study that *C. japonica* is not causing a significant detrimental socio-economic impact on the *O. catharus* fishery at this specific point in time, though this does not imply a definite conclusion by any means. Due to the small sample sizes of fishers, caution is needed in assuming the findings in this study equate to there being no impact from this introduced species on the *O. catharus* fishery.

The relatively small invaded range of *C. japonica* at present may be limiting the actual and perceived impact on *O. catharus*. Though with no evident biological limitations to *C. japonica* spreading throughout most of NZ, it may be that a substantial impact to *O. catharus* will only be realised when a more extensive range expansion of *C. japonica* occurs. The low identification accuracy of *C. japonica* across commercial and recreational sectors highlights an issue that would need addressing if public were to be involved in management of the introduced species. Any research that assists in the information collation on *C. japonica* will further clarify the current and potential impacts of this introduced species. Not only is further research beneficial to NZ, but also to other countries susceptible to the arrival of *C. japonica*. Comprehensively researching the impacts across economic, social and ecological aspects is fundamental in determining the management response required for *C. japonica*.

5. References

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Appendices

Appendix A

Information Sheet (Recreational fishers)

UNIVERSITY OF WAIKATO FACULTY OF SCIENCE

Searching for evidence of impact of a non-native crab on a native crab fishery in New Zealand

I am an Environmental Science student at the University of Waikato. For my Masters thesis, I am undertaking a research project regarding whether there is evidence of impact from a non-native crab on a native crab fishery in New Zealand. The aim of this research is to investigate the decline of the native paddle crab (*Ovalipes catharus*, *Pāpaka*) fishery in Waitematā and Kaipara harbours. The implicit direction of this study is to explore whether the decline of this fishery may be linked to the arrival of the non-native crab (*Charybdis japonica*). I am interested in hearing about your knowledge and views as a recreational fisher on whether you believe there is an association between introduced species and the decline of the paddle crab.

Electronic surveys

I would like to assist you in completing a questionnaire that will last around 20 minutes. Attached is an interview schedule outlining some questions I would like to address. During the questionnaire you are welcome to discuss any other topics you may deem relevant to the research that we may not have covered.

Participant Rights

Your participation in this research is completely voluntary. If you choose to participate, you have the right to:

- I can request to be identified or kept anonymous but that total anonymity cannot be guaranteed.
- Refuse to answer any particular question(s).
- Ask any question(s) about the research at any time during your participation.
- I can stop the interview at any time.
- The research will to the best of her ability, keep my identity confidential in the presentation of the research findings.
- All information will be securely stored in a locked cupboard or computer accessed by password.
- The researcher and her supervisors will be the only people to see the raw data.

It is important that you understand that your involvement in this study is voluntary. While we would be pleased to have you participate, we respect your right to decline. There will be no consequences to you if you decide not to participate. If you decide to discontinue participation at any time, you may do so without providing an explanation. If you choose to withdraw from participation in this research the raw data that belongs to you will not be used (it will be destroyed or provided to you, if possible). All information will be treated in a confidential manner, and your name will not be used in any publication arising out of the research. Please note that participants in this research will own their own raw data and the researchers own the interpretation and analysis of the data.

Confidentiality

I will ensure, to the best of my ability, that you will remain anonymous and that confidentiality will be preserved. Your name will not be used in the write up of the report. I will use pseudonyms (fake names) if necessary. All written notes will be transferred to a computer as soon as possible, along with transcriptions and other information. The computer will be protected with a password that will change frequently and which only I will have access.

If you would like to discuss any aspect of this study please feel free to contact myself on ph +64 27 972 9108 or my supervisors Dr McCormack on ph +64 7 838 4636, Professor Chad Hewitt +64 7 838 4386 or Professor Campbell on ph +64 7 838 4625 (sw233@students.waikato.ac.nz, fiona.mccormack@waikato.ac.nz, chewitt@waikato.ac.nz or marnie.campbell@waikato.ac.nz). We are happy to discuss any aspect of the research with you. Once we have analysed the information we will be emailing you a summary of our findings (if you provide us with your email address) and providing you with an opportunity to provide feedback. You are welcome to contact myself, Dr McCormack, Professor Chad Hewitt or Professor Campbell at that time to discuss any issue relating to the research study.

This study has been approved by the University of Waikato, Faculty of Science and Engineering Social Science Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study should contact the Dr Karsten Zegwaard, Chair of the Human Ethics Subcommittee, Faculty of Science and Engineering, University of Waikato, +64 7 838 4892, k.zegwaard@waikato.ac.nz. The Chair of the Human Ethics Subcommittee is the person nominated to receive complaints from research participants for this study. You will need to quote project number FSEN-2016-1.

Results

The results of this research will be used to complete a report for MPI - biosecurity. A presentation will also be made on the key findings. The findings may also be used in a future journal publication.

By completing this survey I am giving consent for my answers to be used in this research and subsequent reports/publications

Paddle Crab Survey – Recreational fisher

Part I: Background information

- 1) Do you live in the area you fish for paddle crab?
- 2) If no, how much time does it take for you to get to the location where you fish for crab?
- 3) Do you like to go fishing?
- 4) How long have you been a fisher (of any species)?
- 5) Do you fish with your... Family? Extended family? Friends? By yourself?
- 6) Are you teaching your children/grandchildren/nieces/nephews to fish?
- 7) What do you fish for, or harvest?
- 8) Do you fish for paddle crab?
- 9) In the last 12 months, about how many times have you gone fishing for paddle crab?
- 10) Do many other people you know catch paddle crab?
- 11) If yes, about how many people (estimate)?
- 12) What method do you use to catch paddle crab?
- 13) How do you use paddle crab once caught?
- 14) Are there certain times of the year that you fish for crabs?
- 15) If yes, what months do you usually fish for crab?
- 16) Is paddle crab an important food source to ..
 - You/your immediate family?
 - Your extended family?
 - Your friends?
- 17) Would you like to elaborate on this answer?

Part II: Perceptions of change in the fishery

- 18) Have you noticed any changes in the amount of crabs you catch at the main location you fish?

- 19) If yes, how has it changed?
- 20) Has this changed over the last... - 5 years? 10 years? 15 years?
- 19) Do you fish for paddle crab at other locations also?
- 20) If yes, at these other locations, have you noticed changes in the amount you catch?

Part III: Knowledge of *Charybdis japonica* and perceived impacts

- 21) The next few questions are about non-native marine crabs. These are crabs that are brought into New Zealand coastal waters by accident. For example, a ship may come to New Zealand with crab larvae in the ballast or bilge water. These crabs then end up in our waters, where they survive and start to reproduce, which can lead to established populations. Are you aware of this happening in New Zealand?
- 22) How concerned are you currently about non-native crabs appearing in New Zealand's beaches and coastal waters?
- 23) Have you heard of the non-native paddle crab *Charybdis japonica* (commonly known as the Asian paddle crab) before today?
- 24) If yes, what do you know about this crab?
- 25) Do you think you have ever caught one of the non-native crabs?
- 26) Given that the non-native crab is caught and eaten in its native range of East Asia, would you use it if you caught it?
- 27) Do you think the non-native crab could cause harm or benefit to New Zealand? If yes, then...
 - Cause a great deal of harm
 - Cause a little harm
 - Not make much difference
 - Be of some benefit
 - Be of great benefit
 - Don't know
- 28) Would you like to elaborate on your answer?

- 29) How confident are you that it would cause harm or be of benefit?
- Not at all confident
 - Not very confident
 - Somewhat confident
 - Confident
 - Very confident
- 30) Please rate on a scale of 0 to 10 where 0 is "not at all important", 5 is "neutral" and 10 is "extremely important":
- How important is it to you personally that the beach and coastal water is clean and unpolluted?
 - How important is it to you personally that there is plenty of fish or sea life in the water?
 - How important is it to you that the beach and coastal water is safe to be in or on?
- 31) Please tell me how much you feel each of these have a responsibility for keeping NZ's coastal areas free from the non-native crab?
- People who fish or visit New Zealand's beaches and coastal areas?
 - All New Zealanders and visitors to this country, even if they don't fish or visit our beaches and coastal areas?
 - Businesses and industries who use these areas?
 - Regional and local councils?
 - The Government?
- 32) Do you have any other comments you'd like to make about the subject of this survey?

Thank you for taking the time to complete this survey

Appendix B

Information Sheet (Commercial fishers)

UNIVERSITY OF WAIKATO FACULTY OF SCIENCE

Searching for evidence of impact of a non-native crab on a native crab fishery in New Zealand

I am an Environmental Science student at the University of Waikato. For my Masters thesis, I am undertaking a research project regarding whether there is evidence of impact from a non-native crab on a native crab fishery in New Zealand. The aim of this research is to investigate the decline of the native paddle crab (*Ovalipes catharus*, *Pāpaka*) fishery in Waitematā and Kaipara harbours. The implicit direction of this study is to explore whether the decline of this fishery may be linked to the arrival of the non-native crab (*Charybdis japonica*). I am interested in hearing about your knowledge and views on whether you believe there is an association between introduced species and the decline of the paddle crab.

Semi-Structured interviews

I would like to conduct a semi-structured interview with you that will last 30 minutes to an hour. Attached is an interview schedule outlining some questions I would like to address. During the interview you are welcome to discuss any other topics you may deem relevant to the research that we may not have covered.

Participant Rights

Your participation in this research is completely voluntary. If you choose to participate, you have the right to:

- Refuse to answer any particular question(s).
- Ask any question(s) about the research at any time during your participation.
- Withdraw from the research up to three weeks after the interview/participant observation.
- Decline to be audio-recorded and have the recorder stopped at anytime.
- Request that any material be erased.

It is important that you understand that your involvement in this study is voluntary. While we would be pleased to have you participate, we respect your right to decline. There will be no consequences to you if you decide not to participate. If you decide to discontinue participation at any time, you may do so without providing an explanation. If you choose to withdraw from participation in this research the raw data that belongs to you will not be used (it will be destroyed or provided to you, if possible). All information will be treated in a confidential manner, and your name will not be used in any publication arising out of the research. All of the survey research data will be kept in a locked cabinet in the office of Jacinta Forde. Please note that participants in this research will own their own raw data and the researchers own the interpretation and analysis of the data.

Confidentiality

I will ensure, to the best of my ability, that you will remain anonymous and that confidentiality will be preserved. Your name will not be used in the write up of the report. I will use pseudonyms (fake names) if necessary. All written notes will be transferred to a computer as soon as possible, along with transcriptions and other information. The computer will be protected with a password that will change frequently and which only I will have access.

If you would like to discuss any aspect of this study please feel free to contact myself on ph +64 7 578 5927 or my supervisors Dr McCormack on ph +64 7 838 4636, Professor Chad Hewitt +64 7 838 4386 or Professor Campbell on ph +64 7 838 4625 (sw233@students.waikato.ac.nz, fiona.mccormack@waikato.ac.nz, chewitt@waikato.ac.nz or marnie.campbell@waikato.ac.nz). We are happy to discuss any aspect of the research with you. Once we have analysed the information we will be emailing you a summary of our findings (if you provide us with your email address) and providing you with an opportunity to provide feedback. You are welcome to contact myself, Dr McCormack, Professor Chad Hewitt or Professor Campbell at that time to discuss any issue relating to the research study.

This study has been approved by the University of Waikato, Faculty of Science and Engineering Social Science Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study should contact the Dr Karsten Zegwaard, Chair of the Human Ethics Subcommittee, Faculty of Science and Engineering, University of Waikato, +64 7 838 4892, k.zegwaard@waikato.ac.nz. The Chair of the Human Ethics Subcommittee is the person nominated to receive complaints from research participants for this study. You will need to quote project number FSEN-2016-1.

Results

The results of this research will be used to complete a report for MPI - biosecurity. A presentation will also be made on the key findings. The findings may also be used in a future journal publication.

If you would like to take part or have any questions in regards to the research project, please feel free to contact me:

Shannon Weaver

sw233@students.waikato.ac.nz

+64 7 578 5927

Researcher

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Supervisor

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Supervisor

**UNIVERSITY OF WAIKATO
FACULTY OF ARTS & SOCIAL SCIENCES**

PARTICIPANT CONSENT FORM

Research Aim: Searching for evidence of impact of a non-native crab on a native crab fishery in New Zealand.

I have received a copy of the Information Sheet describing the research project and understand that:

- My participation is voluntary.
- I can ask further questions about the research at any time during my participation.
- I can withdraw my participation at any time up to three weeks after the interview.
- I do not have to answer questions unless I am happy to talk about the topic.
- I can stop the interview at any time.
- I can ask to have the recording device turned off at any time.
- The researcher will, to the best of her ability, keep my identity confidential in the presentation of the research findings.
- All information will be stored and secured in a locked cupboard or computer accessible by password.
- The researcher and her supervisors will be the only people to see the raw data.
- I can request to be identified or kept anonymous but that total anonymity cannot be guaranteed.

When I sign this consent form, I will retain ownership of my interview, but I give consent for the researcher to use the interview for the purposes of the research outlined in the Information Sheet.

Please complete the following checklist. Tick [✓] the appropriate box for each point.	YES	NO
<i>I wish to remain anonymous.</i>		
<i>I wish to view the transcript of the interview.</i>		
<i>I wish to receive a copy of the findings.</i>		

Participant : _____ Signature : _____ Date : _____ Contact Details : _____ _____ _____	Researcher : _____ Signature : _____ Date : _____ Contact Details : _____ _____ _____
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Paddle Crab Survey – Commercial Fisher

Researcher: Shannon Weaver

Participant name: _____

Institution: University of Waikato

Interview date: _____

Supervisor: Prof Marnie Campbell

Part I: Background information

- 1) How long have you lived in this area?
- 2) For how many years have you been a commercial fisher? (Of any fish stock)
- 3) Who taught you how to fish?
- 4) Do you enjoy your work?
- 5) Do you socialize with other fishers?
- 6) Are you teaching your children how to fish for a living or would you in the future?
- 7) Do you own and operate your own boat?
- 8) If yes, what is the size of your boat?
- 9) If yes, how many crew do you have?
- 10) What gear do you use for catching paddle crabs?
- 11) Has the gear you use changed over time? If so, how?
- 12) How much time do you spend fishing for paddle crab?
- 13) Does the time you spend fishing for crab vary seasonally?
- 14) Does the time you spend fishing for crab change year by year?

Part II: Perceptions of change in the fishery

- 15) How much paddle crab would you catch in a season?
- 16) Has the amount you catch now changed from...5 years ago? 10 years ago? 15 years ago?
- 17) Can you earn a decent living from paddle crab alone?

- 18) Has this changed from...5 years ago? 10 years ago? 15 years ago?
- 19) Do you fish commercially fish for other stock?
- 21) If yes, what gear do you use for this and how much time do you spend on this?
- 22) Do you have any other sources of employment through the year?
- 23) Do you own quota for paddle crab?
- 24) If yes, how much?
- 25) Has the value of the quota changed from...5 years ago? 10 years ago? 15 years ago?
- 26) Do you have Annual Catch Entitlement (ACE) quota for paddle crab? If so, how much?
- 27) Has the ACE price changed...Recently? In the last 5 years? 10 years? 15 years?
- 28) Do you own quota or ACE quota for other stock?
- 29) Is there a Licensed Fish Receiver (LFR) in your area?
- 30) What is the current port price for paddle crab?
- 31) Has the port price changed...Recently? In the last 5 years? 10 years? 15 years?
- 32) How long have you fished commercially for paddle crab (*Ovalipes catharus*)?

Part III: Knowledge of *Charybdis japonica* and perceived impacts

- 33) Have you noticed the non-native paddle crab (*Charybdis japonica*) in your catch?
- 34) If yes, when did you start noticing the non-native crab in your catch?
- 35) If yes, do you think the non-native crab has increased in your catch over time?
- 36) Do you think the non-native crab has had an impact on the paddle crab fishery?
- 37) If yes, can you describe some of the impacts you are aware of?
- 38) Have paddle crab fishers left the fishery/ the region/ commercial fishing altogether?
- 39) If yes, do you think this is because of the non-native crab?
- 40) What are some of the things that fishers have done to deal with changes in the paddle crab fishery?
- 41) Do you think the non-native crab could have commercial value?
- 42) If yes, could this lead to a new fishery?
- 43) Is there anything else regarding the topics covered in this survey that you would like to add?

Thank you for taking the time to complete this survey

Appendix C

Iwi	Hapu	Rohe
Ngāpuhi		Hokianga, Bay of Islands, Whangarei
Ngātiwai		Bay of Islands to Warkworth and Aotea
Ngāti Rehua Ngāti Whātua		Aotea Whangarei Harbour to Tāmaki, Kaipara Harbour also
	Ngāti Whātua Ōrākei Te Uri-o-Hau	Dargaville, Maungaturoto, Mangawhai, Wellsford, Kaipara Harbour
Ngāti Manuhiri	Ngāti Whātua o Kaipara	Kaipara Harbour Mangawhai, Whangaparoa, Hauturu O Toi, Motuihe, Tiritiri Matangi and other motu in the Waitematā/Hauraki gulf
Ngāti Maru Ngāti Pāoa Ngāi Tai	Ngāi Tai ki Tāmaki	Hauraki Gulf, Thames Hauraki, Waiheke Island Te Arai to Tauranga and Great Barrier Island (Aotea)
Ngāti Tamaterā		Warkworth to Mount Maunganui, Waitematā
Ngāti Whanaunga		Mahurangi Harbour to Waihi Beach
Te Kawerau a maki		Mangawhai Heads to Manukau Harbour
Ngāti Tamaoho		Muriwai, Waitematā, Waiheke Island, Waikato River
Te Ākitai Waiohua		Tāmaki

Appendix D

Dr Karsten Zegwaard

Chair, Human Ethics
Faculty of Science & Engineering
Te Pūtaiao me te Mātauranga Pūkaha
The University of Waikato
Private Bag 3105
Hamilton, New Zealand

Telephone 64-7-838 4892
Email k.zegwaard@waikato.ac.nz



To: Prof Marnie Campbell
Date: 9-2-2016
From: Dr Karsten Zegwaard
Subject: Ethical approval for research
Application # FSEN-2016-1

Dear Marnie

The Faculty of Science and Engineering Human Research ethics sub-committee has considered your proposal "*Did the paddle crab commercial fishery go extinct because of a marine invader? Searching for evidence of impact from a marine non-native species invasion*".

The proposal as attached is approved. If you wish to vary the terms of the approved application in any way, please contact me to request an amendment.

We wish you all the best with your research!

Signed 

Appendix E

Species identification questions

- 1) If I showed you some photos of different paddle crabs could you tell me which one are native and which one is the non-native crab, *Charybdis japonica*?
- 2) Please select which crab you think is the NATIVE paddle crab (*Ovalipes catharus*):

a)



b)



c)



d)

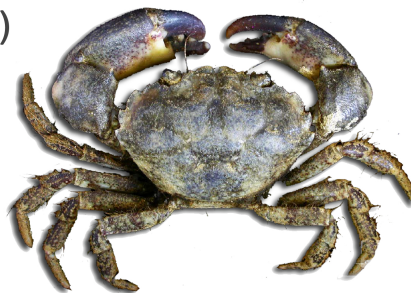


- 3) Please select which crab you think is the NON-NATIVE paddle crab (*Charybdis japonica*):

a)



b)



c)



d)



4) How confident are you at identifying the non-native crab *Charybdis japonica*?

- a) Not at all confident
- b) Not very confident
- c) Somewhat confident
- d) Confident
- e) Very confident

This non-native crab, *Charybdis japonica*, was first found in the Waitematā Harbour in 2000. It has since spread to other locations in New Zealand and is likely to continue to spread further.

