Trial of a Control Programme for Non-Indigenous Crustaceans using *Charybdis japonica* as a case study

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Abbreviations and Units

ARC	Auckland Regional Council
CPUE	Catch per unit effort
ERMANZ	Environmental Risk Management Authority of New Zealand
HSNO	Hazardous Substances and New Organisms Act 1996
IPM	Integrated pest management
LC	Lethal concentration
LD	Lethal dose
MAFBNZ	Ministry of Agriculture and Forestry – Biosecurity New Zealand
RMA	Resource Management Act 1991

1. Executive Summary

The development of methods by which to control and, ultimately, eradicate marine pest species is necessary to safeguard the biodiversity within New Zealand's marine environment. This requires the development of control measures that are suitable for use in a range of different aquatic environments, which do not adversely affect the surrounding natural environment and native species nor disrupt human use of marine resources.

The non-indigenous Japanese swimming crab, *Charybdis japonica* was first detected in New Zealand waters in 2000 and has since become widespread throughout the Waitemata Harbour, Auckland. The presence of species provided an opportunity to develop and test an integrated pest management (IPM) strategy aimed at managing marine crustaceans.

On behalf of Ministry of Agriculture and Forestry – Biosecurity New Zealand, Golder Associates (NZ) Ltd. developed and trialled a "fish-down" method using trapping as a means of reducing the population of *C. japonica* in Turanga Creek, Auckland.

An IPM approach is considered the most viable option for the management of marine crustaceans. Based upon the literature review and laboratory tests, it was considered that trapping and carbaryl baits were the most feasible components of an integrated management system for the portunid crab, *C. japonica*. Unfortunately regulatory controls and stakeholder objections over activities in the coastal marine area prevented an effective evaluation of the proposed integrated approach. This inability to field test the efficacy of carbaryl baits within an IPM strategy highlights the difficulty of undertaking research towards the development of effective marine biosecurity tools within the present regulatory framework.

Restricted from implementing an IPM approach, the fish-down method (without poison baits) was trialled in Turanga Creek. Early results suggested that the control trial was having an effect as larger males were apparently being removed from the population. The control trial was not, however, successful in the long term as the catch rate of the target species returned to original levels during the nine months following the trial. This is considered to be largely a result of the expanding size of the *C. japonica* population in the Waitemata harbour prior to the trial and continued migration of crabs into the estuary.

The effects of hyperstability and changes in catchability of *C. japonica* during the trial may have influenced the assessment of CPUE data throughout the control period. The method did, however, have a range of benefits, including the ease of setup and application of the traps in a range of marine environments, the low cost of equipment and the low impact on natural habitats and fauna.

2. Introduction

2.1. PURPOSE AND SCOPE

Management of newly-introduced and established marine pest species requires the development of control measures that are suitable for use in a range of different aquatic environments and that do not adversely affect the surrounding natural environment and native species, nor disrupt human use of marine resources. A diverse range of techniques for the control and, potentially, the eradiation of non-indigenous marine species already exist (e.g. McEnnulty et al. 2000, 2002; Browne & Jones 2006a and references therein); however, the methods available require refinement and modification for the specific marine pests and habitats occurring in New Zealand waters.

The presence of the non-indigenous Japanese swimming crab, *Charybdis japonica*, in Waitemata Harbour, Auckland provided an opportunity to devise and test an integrated pest management (IPM) strategy aimed at controlling crustacean species. The intention was to develop a “toolbox” of control techniques for use against *C. japonica* and for any future incursions of pest crab species such as the European green crab, *Carcinus maenas* and the Chinese mitten crab, *Eriocheir sinensis*.

On behalf of Ministry of Agriculture and Forestry – Biosecurity New Zealand (MAFBNZ), Golder Associates (NZ) Ltd. (Golder) developed and trialled a control method as a means of reducing the population of *C. japonica* in Turanga Creek, Auckland.

This report provides:

- an overview of the research conducted prior to the final control trial;
- detail of the preparation required for the trial, including permit and consent applications;
- results of the final control trial; and
- an assessment of the fish-down method for managing non-indigenous Crustacea.

2.2. PRE-TRIAL RESEARCH

2.2.1. Review of Control Techniques

A detailed literature review and assessment of control techniques was undertaken as an initial step in developing the final control strategy (Browne & Jones 2006a). Control techniques considered to be potentially applicable to marine crustacea as well as methods previously employed against other known invasive crabs such as *C. maenas*, *E. sinensis* and the blue crab *Callinectes sapidus* were included in the review.

The review highlighted several categories of pest control methodologies, including environmental modification, biological control, physical removal, sterilization and chemical control methods (Browne & Jones 2006a). Specific techniques in each of these five categories were assessed for their potential in controlling non-indigenous crustacean species. This included an evaluation of the efficacy of each application technique, advantages and constraints of using the technique in marine environments, ecological impacts and cost-effectiveness.

Based on the findings of this review, it was concluded that the best strategy would be the combination of several control methods into an integrated pest management (IPM) strategy, thereby utilising individual strengths of multiple methods to mitigate the growth and spread of the target pest population. It was also apparent that the most appropriate and cost-effective IPM strategy was likely to include a combination of passive collection by trapping and chemical control to reduce the *C. japonica* population, as well as physical barriers to restrict migration of crabs in or out of the trial area.

2.2.2. Laboratory Trials

Prior to implementing the final IPM strategy, it was considered necessary to conduct laboratory trials for a small-scale evaluation of control techniques and to determine parameters for chemical control options (Browne & Jones 2006b). The New Zealand paddle crab, *Ovalipes catharus* was used as a species surrogate for *C. japonica* for the majority of the trials owing to the limited availability of wild-caught *C. japonica* during the winter season when the trials were undertaken, and the cost-effectiveness of obtaining a large number of live specimens from local fish markets. Methods that proved to be successful on *O. catharus* were subsequently tested on *C. japonica*.

Barrier options identified by the review included chemical barriers and a “bubble curtain”, both of which provided potential methods of limiting crab movement while not causing a navigation hazard for vessel traffic. The rationale for the chemical barrier was that the mobility of crabs would be adversely affected by the slow release of acutely toxic substances into the water column from chemically-treated rope or other materials, thereby limiting migration in or out of the study area. The bubble curtain was considered as a barrier option as this is a method that has been used to control the movement of fish species, particularly in the vicinity of marine construction activities (e.g. Kingett Mitchell 2001 and references therein). The advantage of the bubble curtain is that it does not require the use of hazardous substances and does not restrict vessel movement. The results of the laboratory trials indicated, however, that neither the chemical barriers nor the bubble curtain were affective barriers to the movement of highly-mobile crab species (Browne & Jones 2006b).

Laboratory testing also included an evaluation of four chemical formulations for use as control options for portunid crabs. Formulations of carbaryl, copper oxychloride, emamectin benzoate and hydrated lime were administered at a range of concentrations as aqueous solutions and incorporated in a food item (bait) to establish lethal concentrations (LC_{50}) and doses (LD_{50}). A detailed description of the chemical formulations and the rationale for using these for the control of Crustacea is included in Browne & Jones (2006b).

Emamectin benzoate and carbaryl were the most successful chemical treatments for causing acute toxicity in portunid crabs within 24 hours when administered both in an aqueous solution and as bait. Carbaryl was determined to be the best of the four formulations when administered as a bait (Browne & Jones 2006b). Carbaryl-treated bait was also readily consumed by wild-caught *C. japonica*, resulting in mortality within 24 hours (Browne & Jones 2006b).

2.2.3. Field Surveys

Field surveys were also required prior to commencing the final control trial to establish a suitable trial location and to conduct preliminary tests to assess the efficacy of opera-house crab traps.

The location of the final control trial needed to be isolated or semi-isolated from the rest of the Waitemata Harbour to minimise the effects of migration by *C. japonica* into the area during the trial. The study area also needed to be of a size that would allow an appropriate trap density to be maintained throughout the trial and within budget constraints; and populated by *C. japonica* at densities that would enable any reduction in the population size to be evident during the trial period. A nearby boat ramp was required for easy access and a relatively low recreational use of the trial area was preferable so as to minimise interference of the traps and reduce disturbance to public activities.

Several areas were investigated as suitable trial locations, including Orewa, Weiti, Okura and Whitford estuaries and the estuarine waterways of Upper Waitemata Harbour. The traps used were an “opera-house” design (e.g. Vasquez Archdale et al. 2003, 2006; Vasquez Archdale & Kuwahara 2005) and a trial of different bait types was undertaken during the field surveys, as described in Jones & Browne (2006).

Charybdis japonica were captured in Weiti, Upper Waitemata and Whitford estuaries, but were not found at Orewa or Okura (Jones & Browne 2006). Thirty crabs were caught from 38 traps deployed over two days at Weiti, 25 crabs were caught from 20 traps deployed overnight in the Upper Waitemata Harbour, and 9 crabs were caught from 20 traps deployed overnight at Whitford.

The field surveys established that the opera-house trap design was suitable for capturing *C. japonica*, while allowing other by-catch species to be released on retrieval of the trap. A combination of baits were tested, including foods that were high in saccharides (based on the findings of Kawamura et al. 1995); however, the type of bait was later shown not to affect trapping success (Jones & Browne 2006).

3. Methods

3.1. PREFERRED IPM STRATEGY

The initial IPM strategy was intended to include trapping and chemical control methods, based on the outcomes of the literature review and laboratory trials. It was proposed that traps would be distributed throughout the trial area to passively collect *C. japonica*. In addition, bait containing a lethal dose of carbaryl would be placed inside traps to kill the occupants of the trap.

The use of chemical baits was proposed to overcome the effects of gear saturation (i.e. where catch probability decreases as the number of individuals inside the trap increases (Salthaug 2002)); thereby increasing catch-per-unit-effort (CPUE). Gear saturation typically occurs when the trap is occupied by a large number of animals preventing others from entering the trap, or by the presence of larger individuals that either prey on or act aggressively towards other, typically smaller, captured crabs (Gust et al. 2002). Other alternative strategies to overcome gear saturation are to shorten the soak time (i.e. the length of time that traps are left in the environment before being emptied of their catch) or increasing the density of traps within the study area (Gust et al. 2002). It was proposed that the use of toxic chemicals within the traps would have the same effect as reducing the soak time without the added expense of the time required to physically retrieve the traps.

3.2. CONSENT AND PERMIT APPLICATIONS

Currently, carbaryl is imported for use as a pesticide in terrestrial environments and is available from garden supply stores. The use of carbaryl during the control trial, however, required applications for resource consent and permission to use a hazardous substance in a manner other than for which it is currently permitted. An application was made to the Environmental Risk Management Authority of New Zealand (ERMANZ) for approval to deploy a hazardous substance in containment under section 31 of the Hazardous Substances and New Organisms Act (HSNO) 1996. An application for approval was required as carbaryl is considered to be acutely toxic, and is included under class 6.1 of the hazardous substance classifications. The application to manufacture crab bait containing 1 g/kg carbaryl was approved in February 2007, with controls in accordance with the relevant provisions of the Act and the Hazardous Substances and New Organisms (Methodology) Order 1998.

An application was also made to Auckland Regional Council (ARC) for resource consent to discharge carbaryl into a waterway under the Resource Management Act (RMA) 1991. Consent was required from ARC for a discretionary activity to discharge contaminants into the coastal environment pursuant to Rule 20.5.6 of the Auckland Regional Coastal Plan. An assessment of environmental effects was produced for this purpose, involving evaluations of the effects of the contaminant on natural coastal character, the marine environment, biological resources, humans, navigation and safety, and recreation, as well as cultural and social effects. This consent was not notified but required written approval of affected parties identified by the consenting authority. The majority of stakeholders responded with written approval to our request for resource consent; however, owing to the negative response from some consulted parties, a decision was made by Golder, with agreement from MAFBNZ, that the submission for resource consent would be withdrawn. The concern of stakeholders was for the effects of the trial on local bivalve (mainly cockle) populations, which were harvested recreationally, and for impacts on Maori artefacts located in the Whitford region.

As a result of the decision to withdraw the application for ARC resource consent to use carbaryl, the final trial methodology was adapted to include a fish-down attempt by trapping only.

3.3. FINAL CONTROL TRIAL METHODOLOGY

3.3.1. Trial location

Results of the pre-trial field surveys identified Whitford and Weiti estuaries as suitable areas in which to conduct the final control trial (Jones & Browne 2006). Turanga Creek, an estuarine section of Whitford embayment, was chosen as the location for the final control trial for the following reasons:

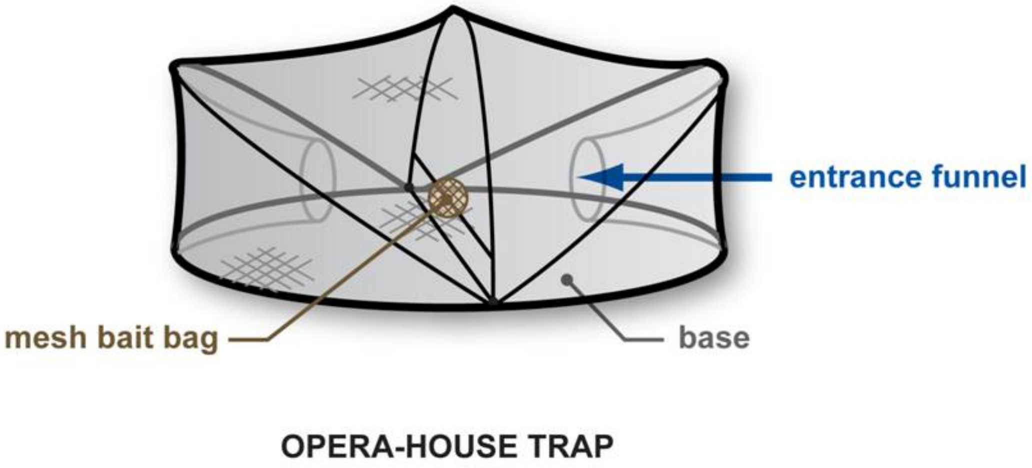
- Population densities of *C. japonica* present in January 2006 suggested a population of sufficient size to support the control trial and show evidence of a reduction in population density.
- *C. japonica* were not detected in other areas of the embayment during the pre-trial surveys suggesting that the influence of migration by this species into the control area would be minimal.
- The number of traps required to maintain the required trap density was less in Turanga Creek than in Weiti Estuary.
- Disruption to public activities was less likely in Turanga Creek than Weiti Estuary owing to a lower amount of recreational use.
- The trial area was easily accessible via a boat ramp situated at the upper end of Turanga Creek.

3.3.2. Trap deployment

Traps were of the “opera-house” design (Figure 1; Vasquez Archdale et al. 2003, 2006) and were set in lines of three traps. The distance between trap lines was maintained at approximately <40 m during the trial. This distance was based on the olfactory response of marine crabs to bait, which are reported to detect and responded positively to attractants at a distance of up to 48 m (e.g. Skajaa et al. 1998).

Forty-four lines of three traps (i.e. 132 traps in total) were set within Turanga Creek on 26 and 27 February 2007 (Figure 2). The placement of traps attempted to target known locations of preferred *C. japonica* habitat, as determined from the pre-trial trapping effort (Jones & Browne 2006). This included placement of traps in the vicinity of hard structures such as wharves, mooring piles and channel markers, as well as the deeper sections of the creek.

Figure 1: Opera-house trap design.



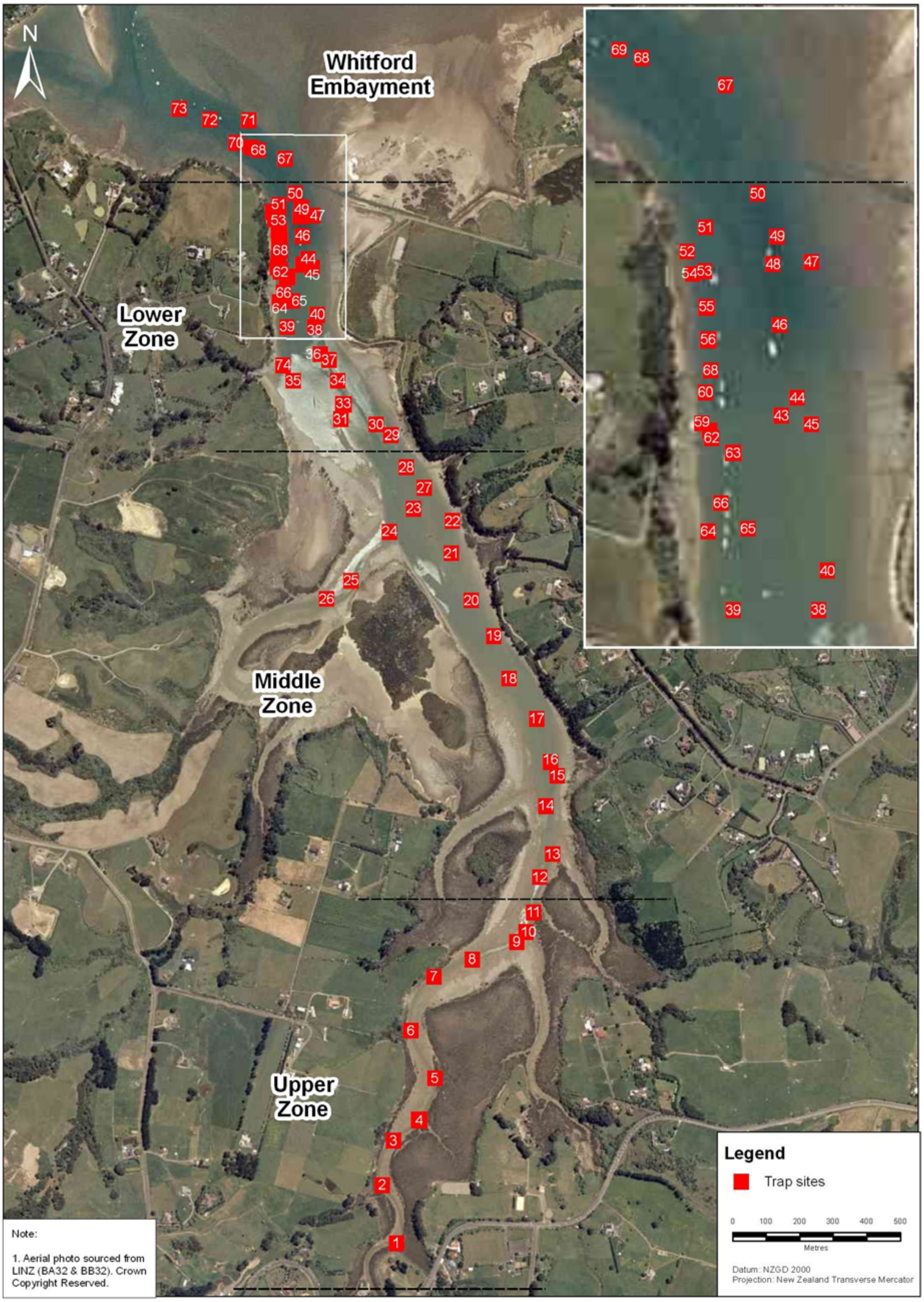
Throughout the trial, the placement of traps was adjusted to target “hot-spot” areas where *C. japonica* were frequently caught previously. Traps were distributed throughout the entire study area by maintaining fixed trap lines, with additional traps relocated to target hot spots.

The traps were baited with previously frozen pilchards, chosen because of their oily consistency and, hence, sustained release of olfactory cues. The traps were deployed parallel to the current to increase the chance of crabs encountering the traps when travelling up the concentration gradient of odour flowing down current from a trap line (Vasquez Archdale et al. 2003).

The soak time for traps varied between 24 and 48 hours. A minimum soak time of 24 hours was selected for the trial based on previous research reporting that a soak time of 24 hours captured the highest number of crabs, usually as a result of more traps being occupied rather than capturing a greater number of crabs per trap (Gust et al. 2002). However, access to shallow or narrow channel areas of the study area was restricted during low tide, therefore limiting the amount of time available for the field team to empty and re-set traps. Two options were considered to overcome this limitation: (a) extend the soak time to 48 hours (i.e. empty traps every second day) or (b) have two teams operating to clear all traps within 24 hours. It was considered that a maximum soak time of 48 hours was acceptable, thereby avoiding the extra labour costs of employing an additional field team.

The control trial was initially intended to last approximately 20 - 25 days as this period would simulate the likely length of time for a rapid response programme to a new marine pest incursion. The catch-per-unit-effort (CPUE), which is the total catch divided by the sum of an observable measure of effort associated with the catch (e.g. trap soak hours), and is usually calculated for a defined period of time (but can also be restricted by spatial or other strata) (Maunder et al. 2006). In this case, CPUE was calculated daily as the number of crabs caught per total soak time as per the following:

Figure 2: Trap sites for the fish-down control trial in Turanga Creek, February – April 2007.



Note:

1. Aerial photo sourced from LINZ (BA32 & BB32). Crown Copyright Reserved.

$$CPUE = \frac{\textit{Total number of } \text{Charybdis japonica} \textit{ caught during Day}}{\textit{Total amount of soaking hours of all traps retrieved during Day}}$$

CPUE was monitored daily throughout the trial to assess the efficacy of the control method. Based on a decline in CPUE after 25 days of trapping (e.g. Figures 3 and 4), a decision was made to continue the control trial for two more weeks with the intention of obtaining more definitive data on which to base an assessment of efficacy.

3.3.3. Post-trial monitoring

Four weeks after the initiation of the control programme, a preliminary qualitative assessment was undertaken using SCUBA divers to conduct an underwater visual search to assess the presence of *C. japonica* in Turanga Creek. Two SCUBA divers spent an hour each searching for *C. japonica* on the seafloor and mooring structures in the lower area of Turanga Creek, which previously contained a relatively high, visually detectable crab population.

The trial was followed by seasonal monitoring during autumn, winter and spring. Trap lines were distributed throughout the estuary at the same trap sites as for Week 6 of the control trial and were set for 24 hours over four consecutive nights.

3.3.4. Data collection and assessment

The number of *C. japonica* specimens caught in each trap was recorded on field data sheets and specimens were stored on ice while transported to the laboratory, where they were measured (carapace width) and their physical condition noted. All specimens were then frozen and stored until disposal. Any by-catch were identified and counted on site before being returned to the environment. If positive identification could not be made in the field, a voucher specimen was stored on ice for later taxonomic identification.

The effectiveness of the control method was measured using the daily catch-per-unit-effort (CPUE) data. For instance, for the first day of trap retrieval, the CPUE was calculated as 24 crabs caught divided by a total soak time of 3024 hours (i.e. 63 traps each set for 48 hours), giving a CPUE of 0.0079 crabs per trapping hour.

Figure 3: Daily CPUE for *Charybdis japonica* during the fish-down control trial, February – April 2007.

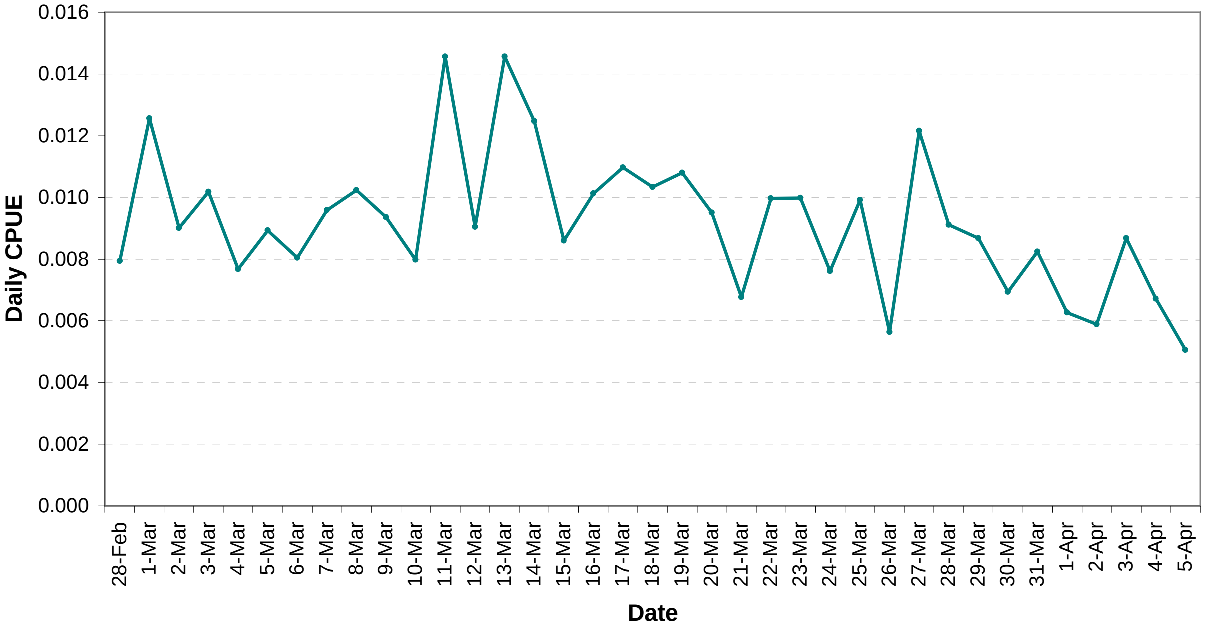
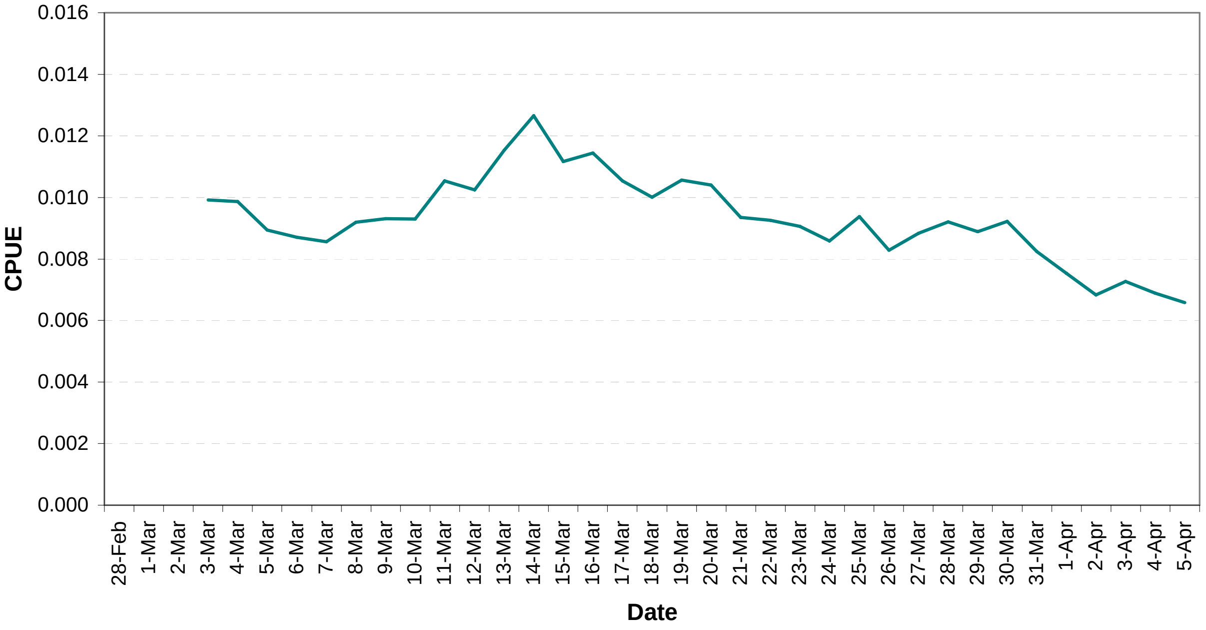


Figure 4: Four-day moving average of daily CPUE for *Charybdis japonica* during the fish-down control trial, February – April 2007.



4. Results

4.1. FISH-DOWN CONTROL PROGRAMME

4.1.1. Trapping technique

The deployment of trap lines was relatively quick and easy, requiring a small vessel with an experienced skipper and two deckhands to add bait to the traps and release the trap line over the side of the vessel into the water. Trap deployment typically took less than a minute to bait traps and ensure the lines had been set parallel to the current. The most restrictive aspect of the trial set-up was movement around the study area as this required vessel access to narrow channels and was limited to periods of higher tides when all areas of the estuary could be reached. Deployment of traps did not require specially-skilled personnel; although an experienced skipper was necessary for safe and effective vessel operation.

The basic costs associated with the control trial are presented in Table 1. These costs do not include items that can vary significantly depending on the location and scale of the pest management programme, such as travel, the time required for set-up prior to starting the trial or for assessment of trial progress, or costs associated with consent and permit applications.

4.1.2. Catch rate of Charybdis japonica

A total of 1004 *C. japonica* were captured during the control trial. Catch data for *C. japonica* and bycatch species are included in Appendix B. Daily CPUE was calculated throughout the trial and ranged from 0.005 to 0.015 (Figure 3). CPUE was, however, highly variable and the four-day moving average of CPUE was calculated to ‘smooth’ this variability for graphical purposes and to better interpret trends in catch rate over the trial period (Figure 4). Average CPUE peaked during the first fortnight and steadily declined over the last four weeks of the trial, eventually dropping to the lowest CPUE calculated throughout the trial period.

Table 1: Basic costs associated with the fish-down control method.

Item	Rate	Amount	Cost
Equipment – traps, leadline, marker buoys, rope	$10 per trap $20 per buoy $500 for rope, leadline	150 traps 50 lines For all trap lines	$1,500 $1,000 $500
Consumables – bait, ice for storage	$50 per week	6 weeks	$300
Vessel hire – small boat and skipper	$1100 per week	6 weeks	$6,600
Personnel – scientific technicians to tend traps	$80/hr for Field Leader $50/hr for Assistant	6 weeks (7.5 hr/day) 6 weeks (7.5 hr/day)	$25,200 $15,750
TOTAL COST			$50,850

Figure 5 illustrates the four-day moving averages of daily CPUE for male and female *C. japonica* separately, which indicates that the catch was dominated by male crabs. The catch rate of female crabs was relatively stable towards the end of the trial period; however, the CPUE of female crabs increased slightly as the CPUE of male crabs declined. The average size, measured as carapace width (mm), varied throughout the trial (Figure 6); however, there were no specific trends in the variability of *C. japonica* size during the control programme.

To assess any spatial trends in catch rate during the trial period, CPUE was calculated separately for three regions of Turanga Creek, which included the upper, middle and lower estuarine regions of the study area. While catch rates were highly variable throughout the trial, the trends illustrated in Figure 7 suggest that some localised reduction in the *C. japonica* population may have occurred during the trial. The CPUE for both the middle and upper regions decreased towards the end of the trial period indicating that the number of crabs in these areas was declining. The catch rate of *C. japonica* in the lower estuary remained relatively constant, possibly as a result of crab migration into the trial area. The presence of *C. japonica* outside of the study area was confirmed by the capture of crabs at Sites 68 - 73, which were positioned outside the study area in the Whitford embayment (Figure 2).

CPUE was also compared between traps that remained at fixed locations throughout the trial and those that were moved around the study area to target ‘hotspot’ areas with higher catch rates of *C. japonica* (Figure 8). The catch rate of traps that remained in constant positions was relatively stable throughout the control trial, although an increase in CPUE occurred during Week 5. Traps that were moved during the control programme to target hotspot area had a greater CPUE for the majority of the trial, which is to be expected given that these were placed in areas with a higher abundance of crabs. The decrease in CPUE towards the end of the trial suggests that the density of *C. japonica* in the hotspot areas may have been declining as a result of the trapping efforts.

4.2. MONITORING

During the preliminary underwater visual search, divers did not observe any crabs on the seafloor but searching around structures on the seabed, i.e. rocks and mooring piles, revealed crabs hiding in crevices and between rocks. Three *C. japonica* specimens were observed during the visual search, which included a gravid female found in the crevice of a mooring pile, a male crab found amongst rocks on the seafloor and a swimming *C. japonica* that could not be captured by the diver. These observations suggested that *C. japonica* was not abundant in Turanga Creek, but present at low densities. Based on these findings and in association with the slight decrease observed for daily CPUE by 21 March 2007, it was decided that the control trial would be continued for an additional two weeks in order to better assess catch rates over an extended period.

Following the completion of the trial, catch rates in the subsequent autumn and spring seasons were equal to those calculated during the trial, and indicate that the fish-down method was not successful in reducing the crab population within Turanga Creek (Figure 9). During the winter season monitoring, an extremely low CPUE was calculated as only two *C. japonica* were captured despite the same fishing effort as for other monitoring periods (Figure 9).

Figure 5: Four-day moving average of daily CPUE for male and female *Charybdis japonica* during the control trial,, February – April 2007.

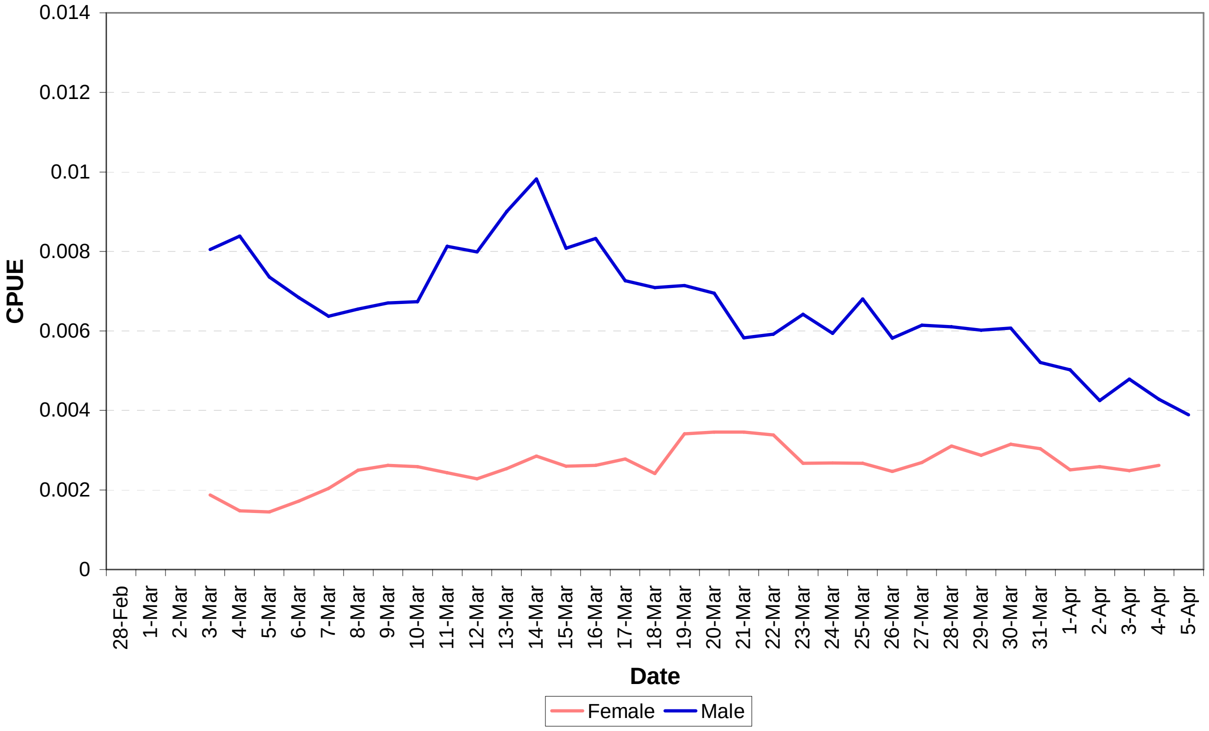


Figure 6: Four-day moving average of average carapace width for *Charybdis japonica* captured during the control trial, February – April 2007.

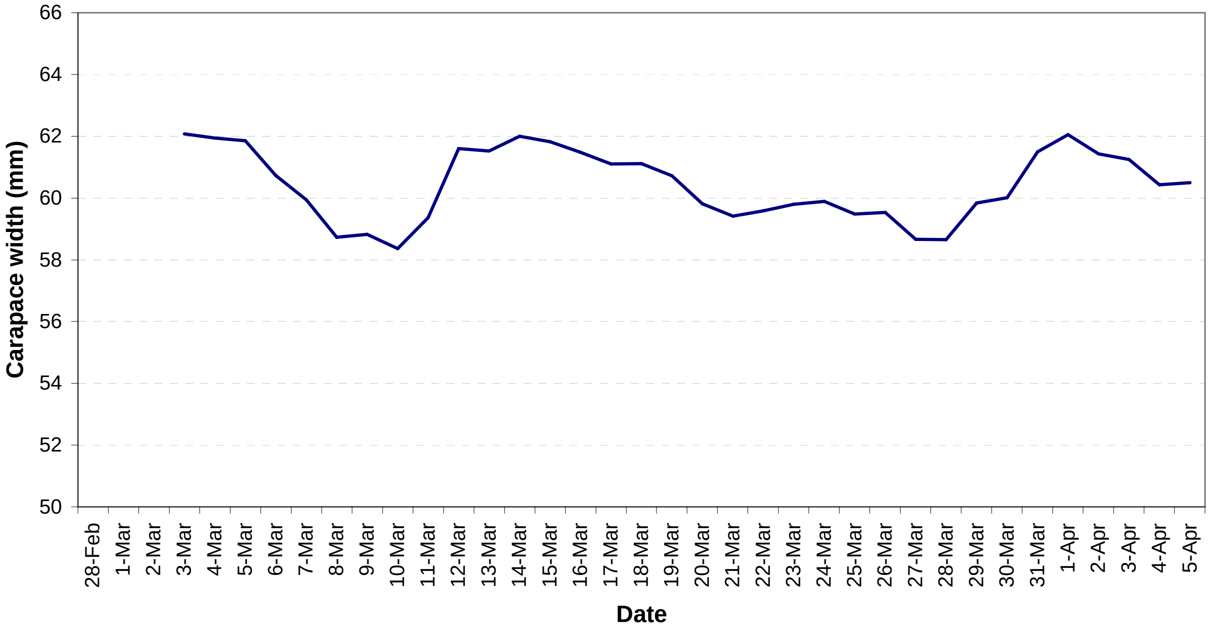


Figure 7: Four-day moving average of daily CPUE for *Charybdis japonica* in the upper, middle and lower regions of Turanga Creek (see Figure 2) during the control trial, February – April 2007.

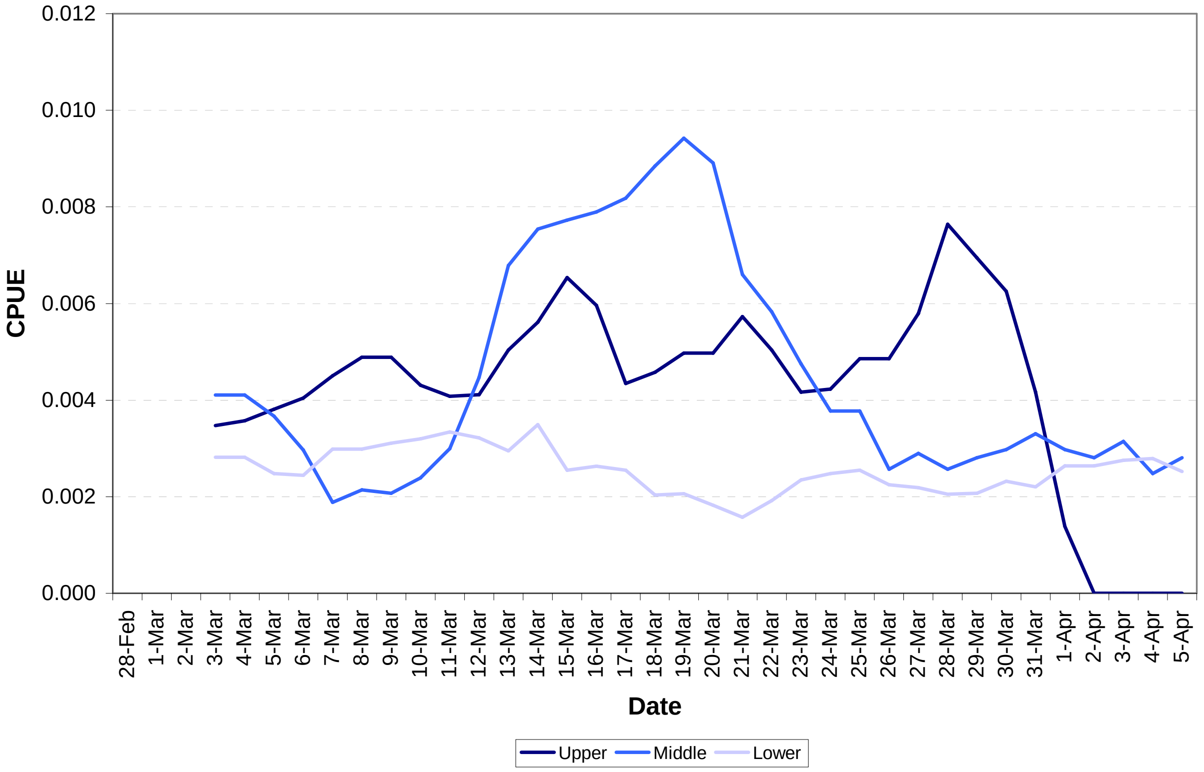


Figure 8: Four-day moving average of daily CPUE for *Charybdis japonica* for traps that were set at fixed locations and moved to target hotspot areas of Turanga Creek during the control trial, February – April 2007.

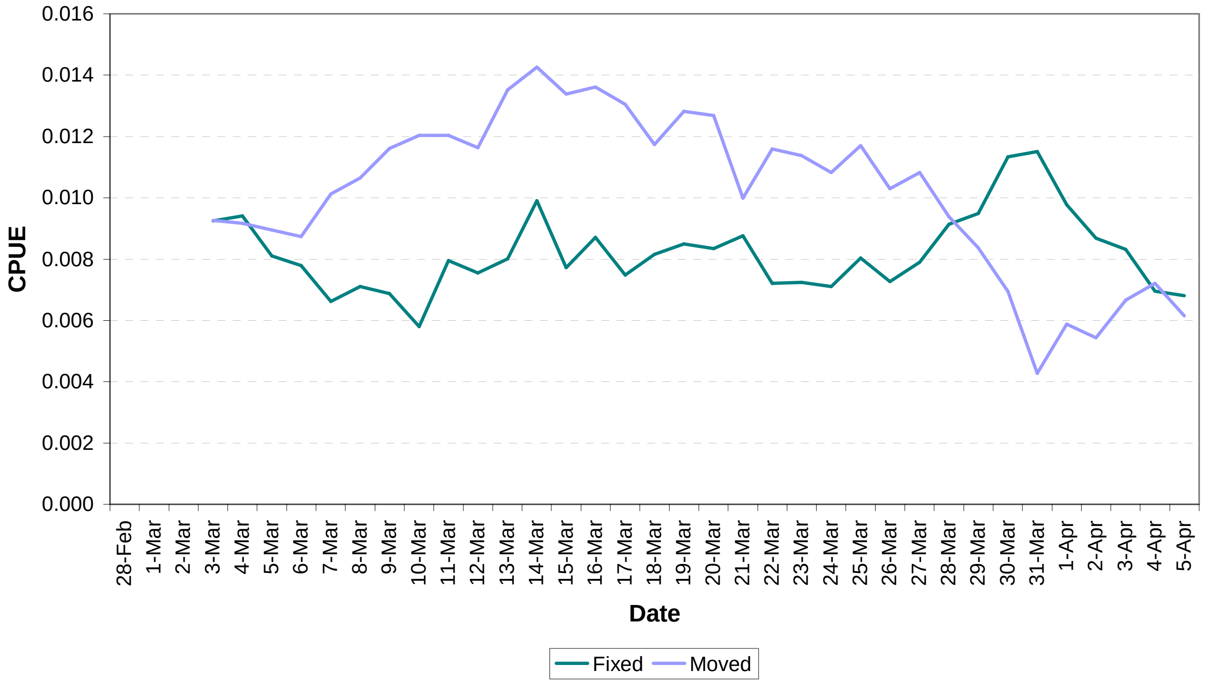
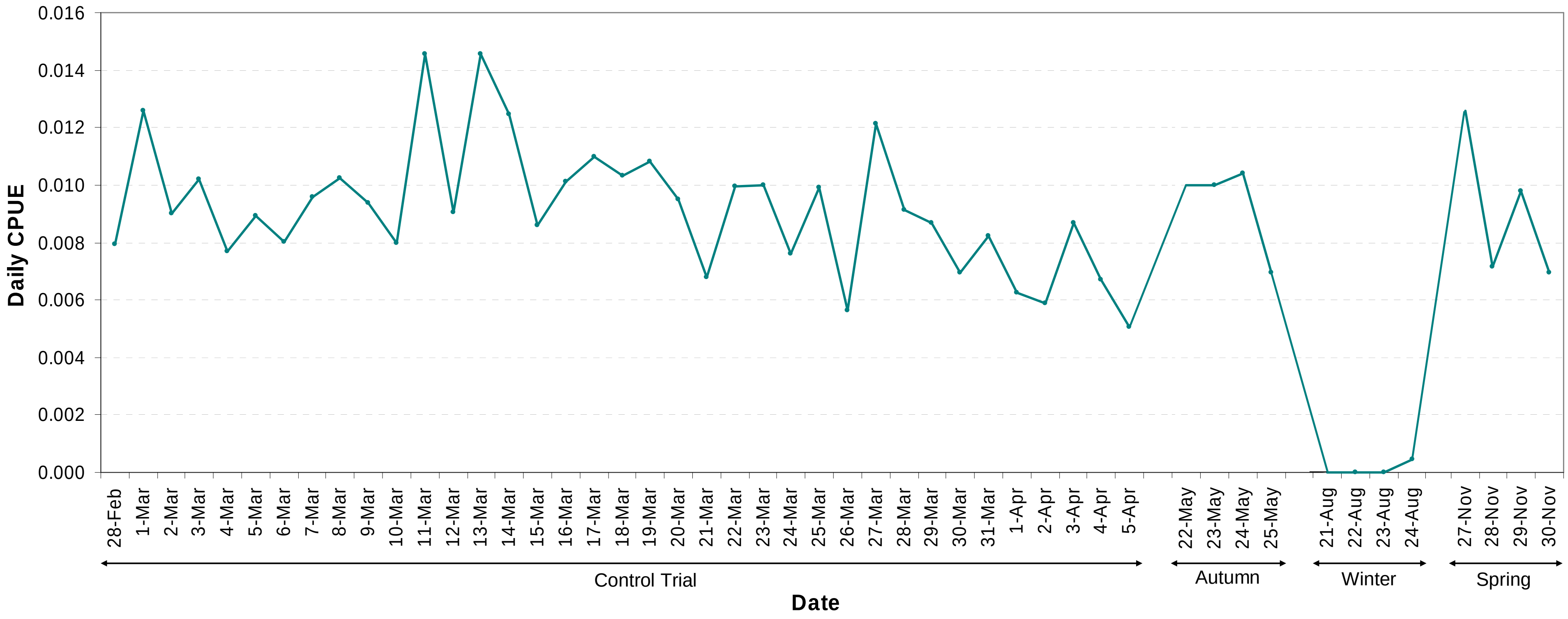


Figure 9: Daily CPUE of *Charybdis japonica* during the control trial (February – April 2007) and monitoring (May, August, and November 2007).



4.2.1. By-catch Data

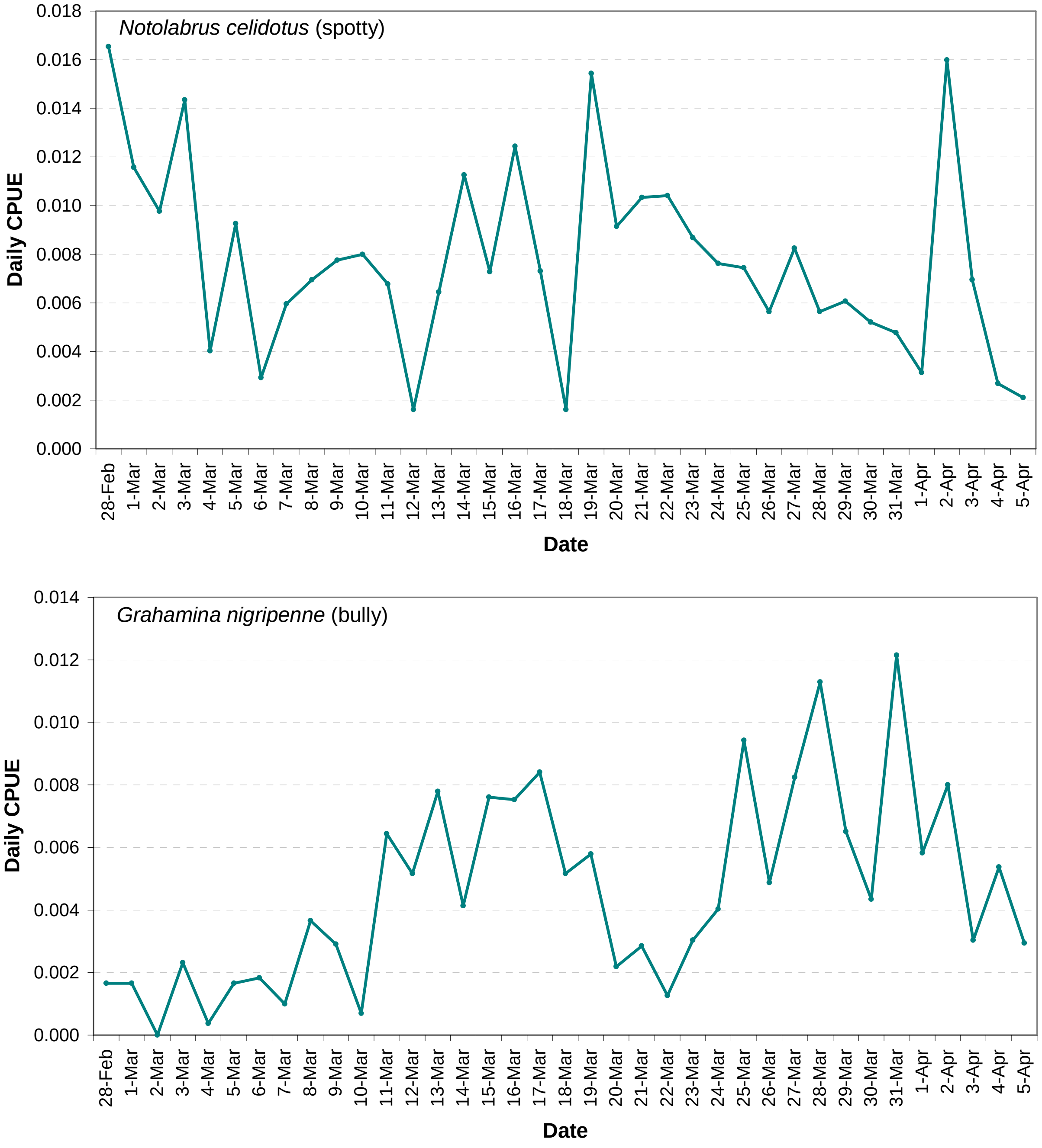
A range of additional fauna were entrained in the traps during the field surveys and control programme (Table 2). Two gastropods, *Cominella* sp. (whelk) and *Lepsiella scobina* (oyster borer) were the most common by-catch species present in the traps, typically aggregating around the bait; however these animals were of a small enough size to exit the trap through the mesh. The shrimp, *Palaemon affinis*, was also commonly present in the traps but was also small enough to exit through the mesh. Of the larger species that were captured and could not escape the traps, *Notolabrus celidotus* (spotty) and *Grahamina nigripenne* (bully) were the most commonly caught species. Daily CPUE of these fish species (Figure 10) was highly variable and did not progressively decline, indicating that abundance levels were largely consistent throughout the trial period.

Table 2: Bycatch species capture during the *Charybdis japonica* control trial and monitoring, February – November 2007.

Species Name	Common Name
Halicarcinus sp.	sea spider
Helice crassa	mud crab
Hemigrapsus crenulatus	hairy crab
Notomithrax sp.	camouflaged crab
Ovalipes catharus	NZ paddle crab
Pagurus sp.	hermit crab
Palaemon affinis	shrimp
Paranephrops planifrons	crayfish
Pilumnus novaezelandiae	hairy crab
Plagusia chabrus	red rock crab.
Austrovenus stutchburyi	cockles
Musculista senhousia	Asian date mussel
Paphies australis	pipi
Perna sp.	mussel
Bursatella glauca	sea slug
Cominella adspersa	whelk
Lepsiella scobina	oyster borer

Species Name	Common Name
Sypharochiton pelliserpentis	chiton
Turbo smaragdus	cats eye
Patiriella sp.	starfish
Aldrichetta forsteri	yellow-eyed mullet
Anguilla sp.	eel
Arripis sp.	kahawai
Geniagnus monopterygius	stargazer
Girella tricuspidata	parore
Grahamina nigripenne	bully
Notolabrus celidotus	spotty
Pagrus auratus	snapper
Rhombosolea plebeia	flounder
Sprattus sp.	sprat
Stigmatopora sp.	piper
Trachurus novaezelandiae	mackerel

Figure 10: Daily CPUE for *Notolabrus celidotus* (spotty) (top) and *Grahamina nigripenne* (bully) (bottom) during the fish-down control trial, February – April 2007.

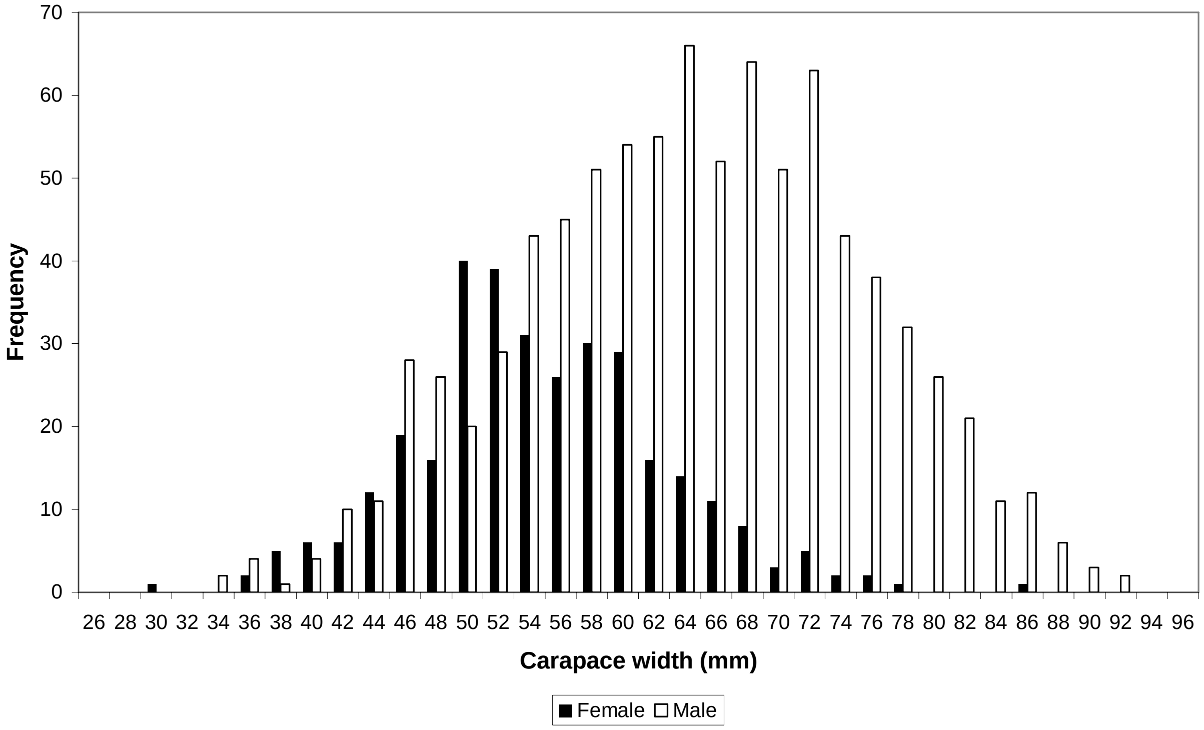


4.3. BIOLOGICAL INFORMATION

Biological information from a total of 1198 *C. japonica* collected during the control trial and monitoring included data on size frequency and sex ratio as well as information on reproductive activity and moulting (Appendix C). Figure 11 displays the size frequency of *C. japonica* from Whitford embayment. The largest crab captured had a carapace width of 92 mm, while the smallest *C. japonica* specimen had a 29 mm carapace width. The average carapace width of *C. japonica* was 54 mm for females, although the highest frequency of female *C. japonica* was of a slightly smaller size at 50 to 52 mm carapace width. The average size of male crabs was 64 mm carapace width, although male *C. japonica* of 68 mm and

72 mm were also relatively common. The female : male sex ratio of *C. japonica* captured during the control programme and monitoring was 1 : 2.7.

Figure 11: Size frequency (carapace width, mm) of *Charybdis japonica* collected from Whitford Embayment, February – November 2007. n = 1198 (325 females, 873 males).



Eleven of the female *C. japonica* were gravid (Figure 12). Six of these were captured during the first 1½ weeks of the control programme and the remaining five gravid females were captured during the week of spring monitoring in November 2007. Two moulted *C. japonica* were captured during the trial on 1 and 13 March 2007 (Figure 12), measuring 72 mm and 63 mm in carapace width, respectively.

Figure 12: A gravid female (left) and moulted *Charybdis japonica* with exuvia (right) captured in Turanga Creek, 2007.

5. Discussion

Many of the principles of commercial fisheries management (such as the method of capture and stock assessment) can be applied to the management of marine pests and both management strategies share some common goals including maximised CPUE and cost-effectiveness (King 1995). Although the long-term objectives of these management strategies differ (as fisheries management aims to ensure the sustainability of the stock while the goal of pest management is to fish down to low levels), both often have a similar outcome with sustainably-managed stocks and managed pest populations generally maintained at levels equal to or below their carrying capacity (i.e. zero net population growth). Thus, many of the principles of commercial fisheries management can be readily applied to the development and assessment of pest control methods for non-indigenous marine species.

Trapping methods are commonly employed for crustacean fisheries (King 1995) and are currently used for capturing *C. japonica* in Asian fisheries (Vasquez Archdale & Kuwahara 2005). A number of studies have been conducted to assess and improve the efficacy of trapping for *C. japonica* (Vasquez Archdale et al. 2003, 2006; Vasquez Archdale & Kuwahara 2005), hence the use of opera-house traps for the control trial was deemed to be the most effective technique by which to collect and remove this non-indigenous species. The fish-down methodology utilised for the control trial also has foundations in fisheries management. In this case, recruitment overfishing is a means of restricting population grown whereby the intensity of fishing effort on a fish stock is increased beyond a certain level, reducing the adult stock to the extent that insufficient offspring are produced to maintain the population (King 1995). Fisheries stock assessment techniques can also be applied to marine pest management for determining the status of the pest population and evaluating the efficacy of control techniques. These principles were used to assess the catch rate data collected during the control trial.

The feasibility of the fish-down method as a management strategy for pest crab populations was also evaluated against criteria used in the initial review of control techniques. This assessment included the advantages and constraints on the method within New Zealand's regulatory framework determined by the RMA, HSNO and Biosecurity Acts as well as health and safety, impacts on existing communities and the cost-effectiveness of the method.

5.1. CATCH RATE ASSESSMENT

Based on the CPUE data collected during the trial, the use of intensive trapping was not successful in fishing-down the population of *C. japonica* in Turanga Creek. The CPUE of *C. japonica* nine months after the trial was similar to that at the initiation of the control programme, indicating this population had returned to its original density (Figure 9). Thus, the abundance of *C. japonica* was not reduced sufficiently to adversely affect the sustainability of the population.

Several factors may be attributed to the trends observed in CPUE during the trial, including the effects of hyperstability, changes in the catchability of the target stock, immigration of *C. japonica* into the trial area, and an inaccurate estimate of the initial population size, as well as the level of effort employed during the control programme. In terms of marine fisheries, hyperstability refers to a phenomenon in which an observed index of stock abundance (e.g. CPUE) remains stable although the abundance of the stock in question is actually declining. This type of relationship typically occurs when fishing is carried out over a small spatial scale and when the search effort is highly efficient, whereby effort concentrates on areas where fish are most abundant and where animals remain concentrated as abundance declines (Hilborn & Walters 1992). To overcome some of the effects of hyperstability on assessment of CPUE data, Hilborn & Walters (1992) suggest spatially stratifying data to analyse catch rate within strata of variable effort. CPUE data from the present trial were, therefore, stratified into upper, middle and lower estuarine regions (Figure 7), which indicated that there may have been a localised reduction in population size in areas of the upper and middle estuary while the catch rate continued to be relatively constant in the areas of high *C. japonica* abundance in the lower estuary.

Analysis of the trends in catch rate was also confounded by the high amount of variation in the CPUE data. Variable CPUE data is, however, a common occurrence when measuring marine fisheries as many factors affect the catchability of the fishery (Maunder et al. 2006). Catch rates of the target species can increase over time as the efficiency of the fishing method increases through fishers learning more about the location and behaviour of the fishery or how to operate the gear more efficiently (Maunder et al. 2006). In the case of the control programme, comparison of CPUE between traps that remained at the same location throughout the trial and those that were moved to target high abundance areas ("hot spots") indicate that the catch rate of traps that remained in fixed positions was relatively consistent throughout the trial compared to traps that were moved about to target those hot spots (Figure 8). This suggests that variability in the CPUE data may have been a result of greater fishing efficiency as a result of the movement of traps to target hot spots.

It is also possible that the catchability of *C. japonica* varied throughout the trial depending on biological traits such as sex, age, size and moult, which could have influenced their vulnerability to trapping (e.g. Maunder et al. 2006). For instance, the comparison of CPUE for male and female crabs (Figure 5) suggests that males dominate the catch, and it is only when the catch rate of male *C. japonica* decreases that a greater number of female crabs are caught, as was evident towards the end of the control programme. The average size of *C. japonica* captured during the control programme was also highly variable, although there were no clear trends evident to suggest that this influenced CPUE (Figure 6). Similarly, there were no definite trends evident in the occurrence of gravid females and moulted crabs in relation to the catch rate of *C. japonica* throughout the control trial. Thus, behaviours related to the sex of crabs may have influenced the catch rate of *C. japonica*, but there are no clear indications that other biological factors directly influenced CPUE during the control trial.

The dynamics of the population and, specifically, the movement of animals into areas previously occupied by other individuals may also act to re-establish a constant density within the fished area (Hilborn & Walters 1992; Maunder et al. 2006). In the case of the *C. japonica* control trial, fished areas may have been re-stocked through the migration of crabs throughout the trial area and by immigration of new recruits into Turanga Creek from the greater Whitford embayment. The presence of *C. japonica* in traps set outside Turanga Creek during the trial (i.e. Sites 68 - 73) suggest that immigration could have sustained catch rates within the trial area, particularly in the lower estuary.

Between the pre-trial field survey in January 2006 and the control trial in February 2007, CPUE increased from 0.00625 to 0.0126 (Jones & Browne 2006, present study), suggesting that the population density had increased, and possibly doubled in the intervening period. It is, therefore, possible that the *C. japonica* population present in Turanga Creek was greater than anticipated, and too large to show a reduction in population density over the trial period and with the amount of fishing effort expended.

5.2. FEASIBILITY ASSESSMENT

Trapping as a pest management tool has the advantage of having minimal environmental, social and cultural impacts, which allows this fish-down technique to be more easily implemented within the present regulatory framework. The effects of trapping on existing marine communities and indigenous species are relatively low. Daily CPUE of bycatch fish species (e.g. Figure 10) did not suggest that populations of native species were declining, or were in other ways affected by the trapping, as most captured fish and other fauna were returned to the environment alive. The traps are also able to be removed from the control area, thus no physical evidence of pest management operations remain in the environment once the control programme is complete.

Fishing methods such as trapping are already well-established as commercial activities and are, therefore, better understood and accepted by the public and accepted within cultural practices. Such methods are, thus, better accommodated within the existing regulatory framework than new or more innovative pest management techniques such as the use of chemical agents.

The health and safety risks associated with the deployment of traps are minimal, as the use of hazardous chemicals or dangerous equipment is not required. Generally, common sense and a standard level of care should be employed as for recreational fishing or trapping, including safe boat handling practices and care with preparing bait or hauling trap lines. One disadvantage of this control method was the potential navigation hazard created by installing a large number of traps in a confined area. In particular, buoys used to mark each trap line could be disruptive to the recreational activities undertaken in the estuary. It should be noted that for the health and safety of personnel it is necessary to have strong and physically fit workers that are capable of hauling heavy traps over long periods of time. Use of a davit and winch to retrieve traps was precluded in this instance by the need to use a small, shallow draft boat in the tidally dominated estuary.

The trapping control method was also limited by the behaviour of the target species and, in this case, "trap-shy" crabs could not be captured (i.e. animals that may not enter the trap owing to competition with other animals or no response to the bait). Hence, an additional technique is required to target the remainder of the *C. japonica* population. The use of poison bait is considered to be a possible way to overcome this limitation, whereby the toxic chemical (e.g. carbaryl) in the bait would leach slowly into the water column, consequently affecting any target organisms in close proximity whether the animal was inside or outside the trap (e.g. Browne & Jones 2006b). The use of chemical control options does, however, require consent from local, regional and national authorities such as regional councils and ERMANZ. This has the potential to be a timely and costly exercise, requiring extensive research of the toxic substances and their effects on the receiving environment prior to use in the natural environment and acceptance from stakeholders for the discharge of chemicals in public waterways.

The behaviour of the target species can also influence the timing for implementing fish-down control methods. For *C. japonica*, it was noted during the pre-trial field surveys and the monitoring period that only a small number of crabs were caught during the winter season (e.g. Figure 9 and Jones & Browne 2006). Similarly, Oikawa et al. (2004) reported that the capture of *C. japonica* increased from zero or one specimen in temperatures of 8.1 - 9.0 °C to catches of 10 - 16 crabs in temperatures of 11.8 - 21.6 °C. This species may, therefore, be averse to searching for food resources during periods of lower temperatures. Management of the population by trapping during colder weather may, subsequently, be unfeasible and fish-down attempts should be restricted to periods when the target species is most responsive to the fishing technique.

The fish-down method was relatively cost-effective to set up as the essential equipment, including opera-house traps, leadline and small anchors were basic and readily-available in New Zealand. One of the limitations of this method, however, was the high expense of labour required to regularly tend the traps. During this trial, technical staff were required as extensive data collection was undertaken; although, these personnel could possibly be replaced with less qualified workers (e.g. student volunteers) to reduce labour costs of future control attempts. Generally, it can be expected that the cost per crab would increase as the abundance of *C. japonica* decreases owing to the increased effort required for capturing the last members of the target population. Consequently, while this fish-down method is relatively inexpensive to set up, the timeframe of control programmes using a fish-down approach would need to be assessed on the basis of whether the amount of effort and associated costs could be sustained for a period long enough to result in eradication or adequate population control.

One of the most significant constraints on the development of an IPM strategy for *C. japonica* was the legislative framework regulating marine pest management in New Zealand. The RMA, HSNO, and Biosecurity Acts provide the regulatory framework that considers a wide range of environmental, social, cultural and economic impacts affecting pest management. However, provisions of the RMA and HSNO Acts are administered in a manner that can oppose pest management activities (e.g. the use of chemical controls) that are otherwise permitted or justified by the Biosecurity Act 1993. This is because uncertainties around the ecological, social and cultural impacts of pest management activities can mean that control activities are not permitted under the RMA and HNSO Acts, whereas uncertainties around adverse impacts caused by non-indigenous species to natural and physical resources, or human health favour rapid response under the Biosecurity Act 1993. This was exemplified by the inability to obtain resource consent to trial carbaryl as a management tool within the time frame of the present study.

6. Conclusions

This project identified that implementation of an integrated pest management (IPM) programme was the most viable option for the management of marine crustaceans. The literature review and laboratory tests determined that trapping and carbaryl baits were the most feasible components of an integrated management system for the portunid crab, *Charybdis japonica*. However, regulatory controls over activities in the coastal marine area prevented field evaluation of an integrated approach using carbaryl baits.

Trapping alone is an inefficient means of eradication and control of mobile crustacea and likely to be ineffective unless it can be sustained over long periods on discrete populations. For target populations equivalent to the size of the *C. japonica* population currently present in Turanga Creek, it would be necessary to increase fishing effort to produce a significantly detrimental impact on the sustainability of the target population. Extending the period of trapping may aid in reducing the crab population to levels that are unsustainable. This may, however, require an increase in the amount of labour required to tend traps regularly. The use of poison baits could also be considered to decrease the influence of gear saturation and to target ‘trap-shy’ crabs.

Given that it was initially concluded that an IPM strategy would provide the most appropriate and cost-effective means of pest control, it is not unexpected that trapping alone did not result in a reduction in the population density of *C. japonica*. An inability to field test the efficacy of carbaryl baits within an IPM strategy was due to legislative constraints and highlights the difficulty of undertaking research towards the development of effective marine biosecurity tools within the present regulatory framework.

A more pro-active approach, in which approvals for use of a range of potentially useful biocides in the marine environment are sought in advance of any incursion is strongly recommended.

Overall, the fish-down method using opera-house crab traps was not successful in controlling or reducing the *C. japonica* population in Turanga Creek, as the catch rate of the target species had returned to original levels by November 2007. This is considered to be largely a result of the increased size of the *C. japonica* population prior to the trial and continued migration of crabs into the estuary. The effects of hyperstability and changes in catchability of *C. japonica* during the trial may have influenced the assessment of CPUE data throughout the trial. This method did, however, have a range of benefits, including the ease of set up and application of the traps in a range of marine environments, the low cost of equipment, the low impact on natural habitats and fauna, and higher public acceptability.

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