

Targeted surveillance for non-indigenous marine species in New Zealand

Design report for Port Taranaki

MAF Biosecurity Technical Paper No: 2018/61

Prepared for MAF Biosecurity New Zealand
by Don Morrissey, Graeme Inglis and Helen Roulston

ISBN No: 978-1-77665-999-9
ISSN No: 2253-3923

September 2009



Ministry of Agriculture and Forestry
Te Manatū Ahuwhenua, Ngāherehere

Disclaimer

While every effort has been made to ensure that the information in this publication is accurate, the Ministry of Agriculture and Forestry does not accept any responsibility or liability for error or omission of fact, interpretation or opinion that may be present, nor for the consequences of any decisions based on this information.

Any view or opinions expressed do not necessarily represent the official view of the Ministry of Agriculture and Forestry.

The information in this report and any accompanying documentation is accurate to the best of the knowledge and belief of the National Institute of Water and Atmospheric Research Ltd (NIWA) acting on behalf of the Ministry of Agriculture and Forestry. While NIWA has exercised all reasonable skill and care in the preparation of information in this report, neither NIWA nor the Ministry of Agriculture and Forestry accept any liability in contract, tort or otherwise for any loss, damage, injury or expense, whether direct, indirect or consequential, arising out of the provision of information in this report.

Requests for further copies should be directed to:

Publication Adviser
MAF Information Bureau
P O Box 2526
WELLINGTON

Telephone: 04-894 0100
Facsimile: 04-894 0300

© Crown Copyright - Ministry of Agriculture and Forestry

Contents	Page
Objectives	1
Target Species	1
Stakeholder engagement and governance	2
Identifying responsibilities within the survey area	2
Obtaining permits to conduct surveillance fieldwork	2
Governance	2
Existing information on the survey location	3
Existing information on marine pests	7
Biophysical conditions	16
Habitat types within the survey area	18
Identification of vector parameters	19
Local constraining factors on surveillance success	25
Port security issues	27
Selection of sampling methods for target species	28
Habitat associations and life histories of the target organisms	28
Selecting life stages to target	28
Sampling methods	28
Surveillance for non-target species	32
Timing of sampling activity	32
Determination of sampling effort	33
Spatial allocation of sampling effort	34
Sample labelling and processing	36
Acknowledgements	39
References	40
Appendices	43
Appendix 1: Letter sent to stakeholders.	43

Appendix 2: Summaries of the habitat associations and life histories of the target species.	45
Appendix 3. Experts contracted to review the habitat summaries and sampling methods for the target species	78
Appendix 4: Sampling data sheets	79

Objectives

The primary objective of the targeted marine surveillance programme is:

- To detect incursions of the target organisms at the identified locations.

The secondary objectives of the targeted marine surveillance programme are:

- To detect incursions of non-target non-indigenous or cryptogenic species not previously recorded in New Zealand.
- To detect incursions of established non-indigenous or cryptogenic species that are exhibiting invasive characteristics (i.e. range extensions of established organisms).

The targeted marine surveillance programme must meet the primary objective. Surveillance should be designed and undertaken with the purpose of maximising the likelihood of successful “containment” of the incursion through providing sufficient detection to maximise the range of management options available, i.e. vector management, local control, etc. The secondary objectives should be considered when designing and undertaking the surveillance programme to increase the likelihood that these will be achieved within the existing design or through minor additions/modifications to this design (these will need to be clearly identified and approved).

TARGET SPECIES

MAF Biosecurity New Zealand has currently identified seven marine organisms that are listed on the unwanted organisms register. These organisms are:

1. Clubbed tunicate, *Styela clava*
2. Northern Pacific seastar, *Asterias amurens*
3. European shore crab, *Carcinus maenas*
4. Green alga *Caulerpa taxifolia*
5. Mediterranean fanworm, *Sabella spallanzanii*
6. Chinese mitten crab, *Eriocheir sinensis*
7. Asian Clam, *Potamocorbula amurens*

An additional three organisms have been identified that are not currently listed as unwanted organisms and are currently known to be established in New Zealand’s coastal waters.

Knowledge of changes in the distribution of these organisms is of interest for current and potential future management purposes. Within the survey design for the primary organisms, opportunities should be explored for detecting these secondary organisms. These organisms are:

8. Asian Date Mussel, *Musculista senhousia*
9. Australian droplet tunicate *Eudistoma elongatum*

Note: the target organism list may be subject to change by MAFBNZ during the course of the surveillance programmes. The colonial ascidian *Didemnum* sp. was originally included in the list of secondary target species but was removed at MAFBNZ’s request in December 2008 (email from Brendan Gould, MAFBNZ, to Don Morrissey, NIWA). Inclusion of additional target species may be considered by MAFBNZ.

Stakeholder engagement and governance

IDENTIFYING RESPONSIBILITIES WITHIN THE SURVEILLANCE AREA

Stakeholder groups with jurisdiction or responsibility within the surveillance location are listed in Table 1.

Table 1 List of stakeholder groups with jurisdiction or responsibility within the surveillance location.

Node/Facility	Responsible group	Contact name
Commercial trading port	Port Taranaki (06 751 0200)	Ray Barlow (Operations Manager/Harbourmaster)
	Port Taranaki (06 751 0200)	John Ireland (Marine Services Manager)
	Port Taranaki (06 751 0200)	Arun Chaudhari (Tanker Terminal Manager)
Consultant on environmental management for port company	CPG New Zealand Ltd (06 759 5990)	Peter Atkinson
New Plymouth Marina	New Plymouth Marina Company	Roy Neatherway (Chairman, 06 751 0973)
Regional council resource management, harbour navigational infrastructure, public wharves, boat ramps	Taranaki Regional council (06 765 7127)	Fred Mclay (Director, Resource Management)
Compliance with fisheries regulations	Ministry of Fisheries (06 755 9311)	Clive Smith (Compliance Officer)
Tapuae Marine Reserve, Sugar Loaf Islands Marine Protected Area, foreshore reserves, marine mammals	Department of Conservation, Taranaki Area Office (06 759 0350)	Bryan Williams (Marine Supervisor)

OBTAINING PERMITS TO CONDUCT SURVEILLANCE FIELDWORK

Contact has been made with all the organisations listed in Table 1 during previous surveys of the port and a letter (see Appendix 1) has been sent to each summarising the purpose of the surveillance programme and, where required, requesting permission to sample. To date, permission has been granted whenever requested and all stakeholders have indicated that their cooperation will continue in the future.

GOVERNANCE

MAF Biosecurity New Zealand

MAF Biosecurity New Zealand is the lead agency in New Zealand's biosecurity system. It is tasked with a "whole of system" leadership role, encompassing economic, environmental, social and cultural outcomes. It also has international trade and animal welfare responsibilities.

Biosecurity activities protect the economy, environment and people of New Zealand from the risks and consequences of the introduction of damaging risk organisms, or mitigate the effects of risk organisms that are already present. Biosecurity surveillance plays a vital role in supporting a wide range of these activities.

The targeted marine surveillance programme is administered and funded by MAFBNZ's Biosecurity Surveillance Group. Queries relating to this programme should be directed to MAFBNZ.

The MAFBNZ contact person for all marine biosecurity surveillance activity is Justin McDonald (phone 04 894 5552, fax 04 894 0736, email justin.mcdonald@maf.govt.nz). Alternatively, the Biosecurity Surveillance Group Manager can be contacted at the following email address: NZBiosecuritySurveillance@maf.govt.nz.

Postal Address:
MAF Biosecurity New Zealand
PO Box 2526
Wellington

NIWA

NIWA has been contracted by MAF Biosecurity New Zealand to design and deliver the surveillance programme to the required specifications.

The NIWA project leaders and contact persons for the targeted surveillance programme are Don Morrissey (NIWA, PO Box 893, Nelson, phone 03 548 1715, fax 03 548 1716, email d.morrissey@niwa.co.nz) and Graeme Inglis (NIWA, PO Box 8602, Riccarton, Christchurch, phone 03 348 8987, fax 03 348 5548, email g.inglis@niwa.co.nz).

Graeme Inglis and Don Morrissey were also responsible for the design of the programme, with inputs from John Carter, Isla Fitridge, Oliver Floerl, Nick Gust, Olivia Johnston, Marie Kospartov, Crispin Middleton, Sheryl Miller, John Oldman, Lisa Peacock, Helen Roulston, Kimberly Seaward, Matt Smith, Kate Willis and Chris Woods. This team also collated existing data.

Field work is carried out by a large team of NIWA staff (over 40 individuals), with additional support from commercial divers from Northern Underwater Technical Services where necessary. Field teams are led by a core of NIWA staff experienced in targeted surveillance: Niki Davey, Crispin Middleton, Sheryl Miller, Don Morrissey, Kate Neill, Lisa Peacock, Matt Smith and Chris Woods. During fieldwork, field teams are generally divided into two groups, each in a separate boat and each including at least one person with previous experience of surveillance. All field team members are under the authority of the field team leader during field work and in communication by telephone or VHF radio. Field team leaders refer to the project leaders as required.

NIWA's Chief Scientist for Biodiversity and Biosecurity, Don Robertson, can be contacted at d.robertson@niwa.co.nz.

Existing information on the survey location

Table 2 lists individuals and groups with local knowledge of the surveillance location.

Table 2 List of individuals/groups with local knowledge of the surveillance location.

Category	Individual/group	Contact name
Commercial trading port	Port Taranaki (06 751 0200)	Ray Barlow (Operations Manager/Harbourmaster) John Ireland (Marine Services Manager) Arun Chaudhari (Tanker Terminal Manager)
Consultant on environmental management for port company	CPG New Zealand Ltd (06 759 5990)	Peter Atkinson
Local authority	Taranaki Regional Council (06 765 7127)	Gary Bedford, Director - Environment Quality Fred McLay, Director - Resource Management Kate Giles (Scientific Officer – Marine Ecology)
Local Authority	New Plymouth District Council (06 759 6060)	
Fisheries regulator	Ministry of Fisheries (06 755 9311)	Clive Smith (Compliance Officer)
National government	Department of Conservation, Taranaki Area Office (06 759 0350)	Bryan Williams (Marine Supervisor)
Research provider (regional museum)	Puke Ariki (06 759 6060)	
Conservation NGO	Royal Forest and Bird Society (Head Office 04 385 7374)	
Marina	New Plymouth Marina Company	Roy Neatherway (Chairman, 06 751 0973)

The following maps show features of the port (Figure 1) and natural and man-made habitats and structures in the survey area (Figure 2). Information on sediments in the harbour was obtained from the navigational charts of the area (Land Information New Zealand Chart Number 4432, published July 2008), from the investigations by Carter *et al.* (1981), and from information on sediment type collected during sled- and grab-sampling during baseline biological surveys by NIWA on behalf of MAFBNZ (see below, unpublished data). Information on shoreline composition (beaches, rocky shores, sea defences, etc.) and artificial structures was obtained from the navigational chart and Google™ Earth. Habitat data were mapped by eye, since we are not aware of any sources of georeferenced information. Information from Google™ Earth is georeferenced and coordinates were used to map the structures in GIS.

Figure 1 Port Taranaki, showing the location of the port on the north Taranaki coast (upper) and port facilities mentioned in the text.

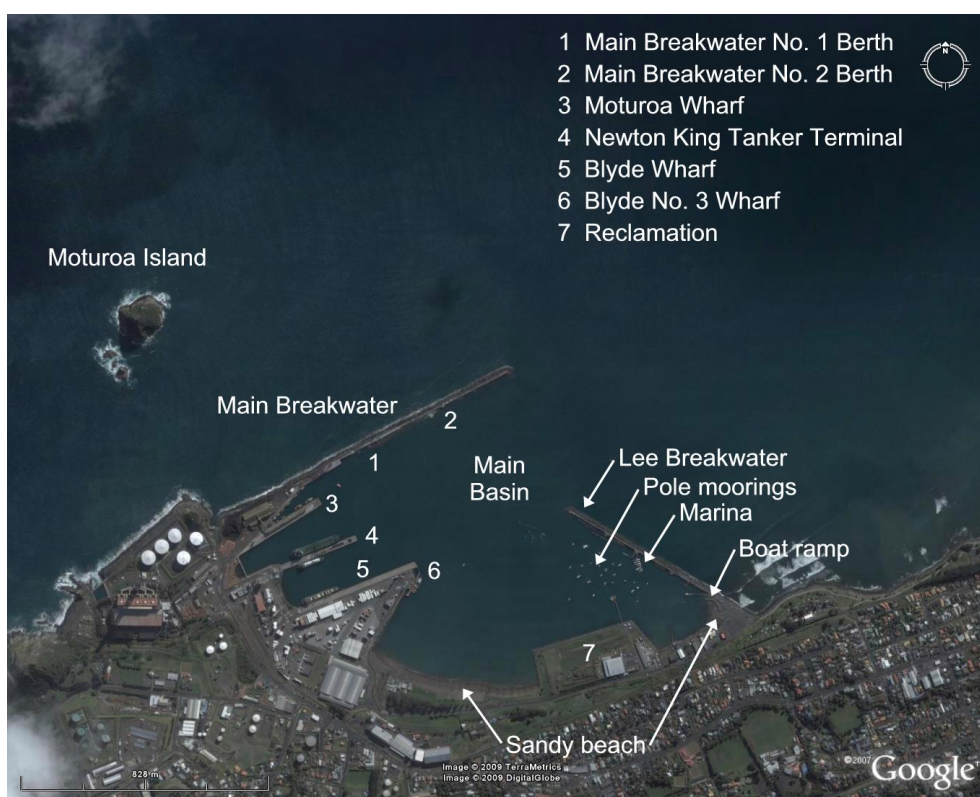
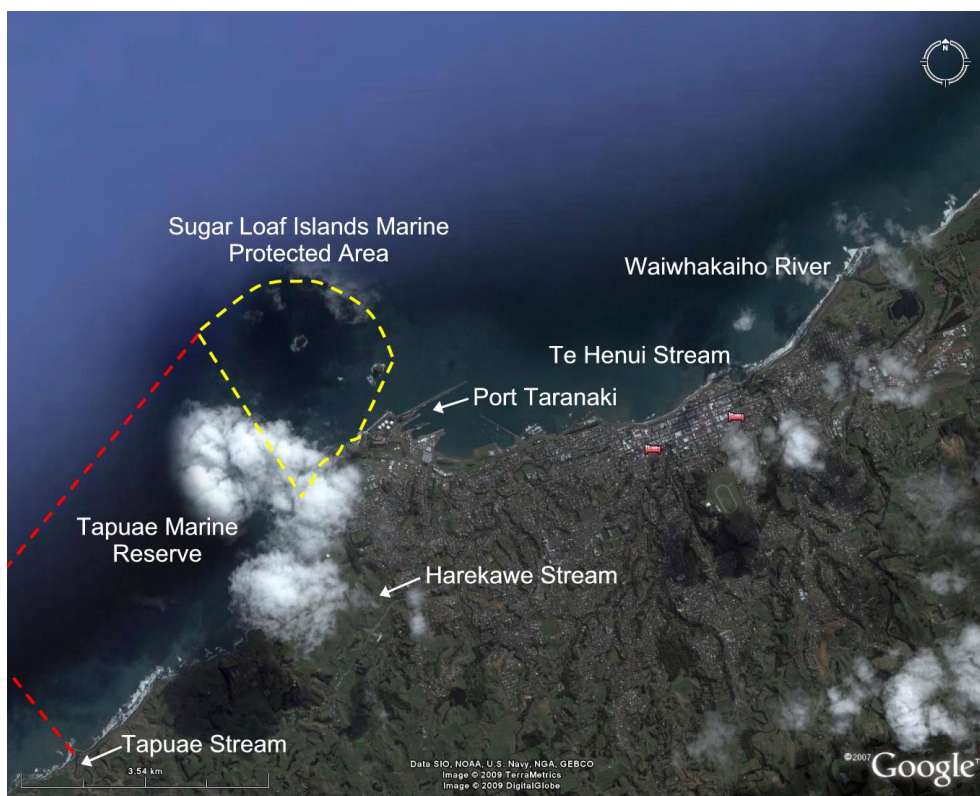
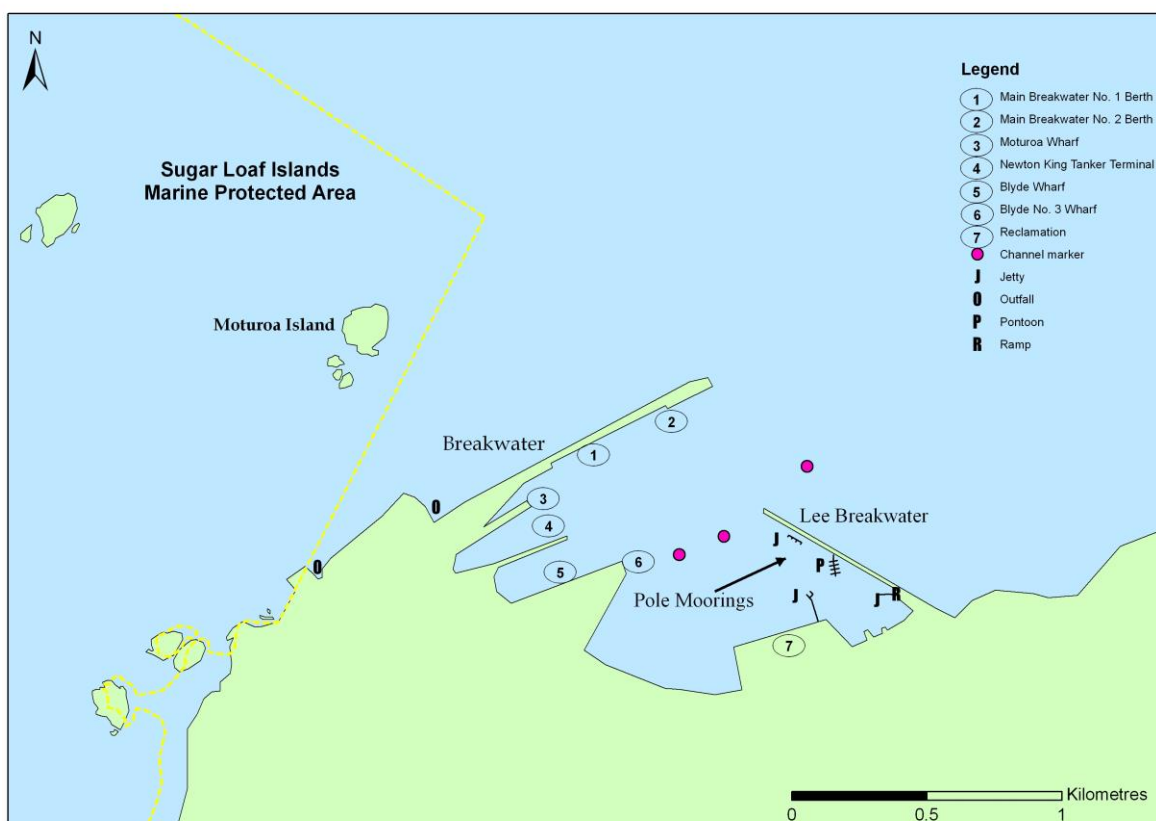
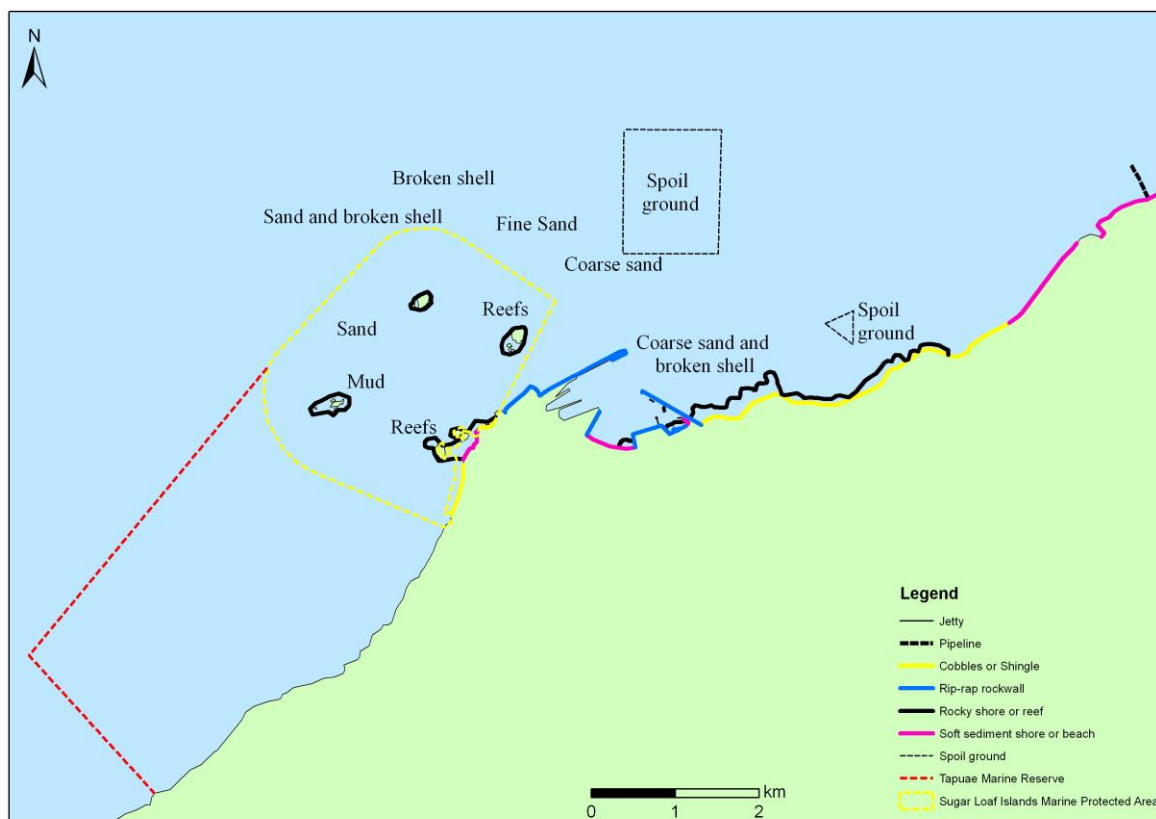


Figure 2 Port Taranaki, showing habitats (upper) and artificial structures (lower) present.



EXISTING INFORMATION ON MARINE PESTS

Over the last two decades, a variety of biological surveys have been carried out in Port Taranaki. Two baseline biological surveys of the Port Taranaki have been done by NIWA on behalf of MAFBNZ, the first in April 2002 (Inglis *et al.* 2006a) and the second in March 2005 (Inglis *et al.* 2008). Results of these surveys are summarised below. The following review of existing biological information on the port is taken from the report of the second survey (Inglis *et al.* 2008).

Several studies have been completed of coastal processes in Port Taranaki and the effects of deepening the Port by dredge (see Carter *et al.* 1981; Gibb 1983; Henwood 1989), but none of these incorporate studies of the ecology of the area. Other than the two NIWA baseline surveys of Port Taranaki (Inglis *et al.* 2006a, 2008), a small number of studies relating to the ecology of the Port and harbour environments do exist, but unfortunately we have been unable to source most of these.

Don (1981) examined the benthic communities within the port and harbour. The study was part of an environmental impact assessment to assess the ecological impact of the Taranaki Harbour Board's proposal to dredge 1.75 million cubic metres of sediment from the harbour, and the disposal of the sediment at an open water site. Twenty-one sublittoral stations were sampled by dredge. Species lists were generated for each station, with a total of 38 species recorded, including the non-indigenous bivalve *Theora lubrica*. The biota was noted to be similar to that recorded in previous studies during the mid-1970s.

Cole and McComb (2000) surveyed the marine fauna off New Plymouth, to the east of Port Taranaki, as part of studies into the potential effects of a proposed nearshore placement site for material dredged from Port Taranaki. They found that the fauna was limited compared to other areas in New Zealand. The only non-indigenous species recorded was the boring sponge *Cliona celata*, found at one kelp forest site at approximately 4 m depth, with a mean abundance of 0.2 colonies per 1-m² quadrat. The assemblage of fishes comprised species common in New Zealand. The dominant habitat encountered was coralline pavement with low species richness. They also found several areas of seaweed (*Ecklonia radiata* and *Carpophyllum maschalocarpum*) forest, which is less common in the region. These seaweed habitats had higher species richness and abundance, and the report recommended that the spoil placement ground be located to avoid areas of seaweed forest. The report found that organism abundance generally declined with depth, and abundances were very low below 10 m depth. Monitoring by drop video camera of the effects of spoil disposal at the inshore site (which has been used since 2004) indicated no effect of the sand placement on the seaweed in the area (Westgate Transport Ltd 2005).

Taylor and MacKenzie (2001) tested the Port Taranaki for the presence of the toxic blooming dinoflagellate *Gymnodinium catenatum*, and detected both resting cysts (sediment samples) and motile cells (phytoplankton samples).

Taranaki Regional Council (TRC) and Port Taranaki jointly monitor the harbour waters for factors that lie outside the areas covered by resource consents. The port state-of-the-environment reporting includes bacteriological water-quality monitoring (five sites, including Ngamotu Beach), sediment quality (seven locations), bioaccumulation of contaminants by mussels (three sites), and invasive species (largely based on existing work commissioned by MAFBNZ, such as the baseline surveys) (Kate Giles, Taranaki Regional Council, pers. comm.). In collaboration with the Department of Conservation, TRC also surveys and removes *Undaria pinnatifida* once or twice a year (results are not published).

RESULTS OF THE BASELINE SURVEYS

An initial baseline survey of Port Taranaki was completed in April 2002 (Inglis *et al.* 2006a). A total of 270 species or higher taxa were identified, consisting of 180 native species, 15 non-indigenous species, 20 cryptogenic species (those whose geographic origins are uncertain) and 55 species indeterminata (taxa for which there is insufficient taxonomic or systematic information available to allow identification to species level). Two non-indigenous species and seven cryptogenic species sampled in Port Taranaki were recorded for the first time in New Zealand waters. These were the hydroid *Eudendrium capillare*, the ascidian *Cnemidocarpa* sp., the cryptogenic portunid crab, *Ovalipes elongatus*, an undescribed pycnogonid (*Achelia* sp. nov. A), an amphipod (*Leucothoe* sp. 1), and five species of sponge (*Esperiopsis* n. sp. 1, *Halichondria* n. sp. 4, *Halichondria* n. sp. 1, *Paraesperella* n. sp. 1, *Phorbas* n. sp. 2).

Since the first survey was completed, several species recorded in it have been re-classified as a result of new information or re-examination of specimens during identification of material from the repeat baseline survey. For example, the ascidian *Cnemidocarpa* sp. was subsequently re-identified as a native species (*Cnemidocarpa nisiotus*). The revised summary statistics for the initial baseline survey of Port Taranaki following re-classification was a total of 267 species, consisting of 178 native species, 14 non-indigenous species, 34 cryptogenic species and 41 species indeterminata.

The 14 non-indigenous organisms described from Port Taranaki included representatives of six major taxonomic groups. The non-indigenous species detected were *Barantolla lepte* (Annelida); *Bugula flabellata*, *Bugula neritina*, *Bugula stolonifera*, *Cryptosula pallasiana*, *Tricellaria inopinata*, *Watersipora arcuata*, *Watersipora subtorquata* (Bryozoa); *Eudendrium capillare* (Cnidaria); *Crassostrea gigas*, *Theora lubrica* (Mollusca); *Griffithsia crassiuscula*, *Polysiphonia sertularioides* (Macroalgae), and *Halisarca dujardini* (Porifera). None of the non-indigenous organisms collected and described from Port Taranaki was on the New Zealand register of unwanted organisms. However, two species included on the Australian Ballast Water Management Advisory Council (ABWMAC) list of unwanted marine species in Australia, the Pacific oyster *Crassostrea gigas*, and cysts of the cryptogenic toxic dinoflagellate *Gymnodinium catenatum*, were present in the Port. Approximately 73% of non-indigenous species (11 of 14) recorded in Port Taranaki initial baseline survey were likely to have been introduced in hull fouling assemblages, 7% via ballast water and 20% could have been introduced by either ballast water or hull fouling vectors.

During the repeat survey in 2005 (Inglis *et al.* 2008), 269 species or higher taxa were recorded, including 180 native species, 13 non-indigenous species, 27 cryptogenic species and 49 species indeterminata. Many species were common to both surveys. Around 54% of the native species, 61% of non-indigenous species, and 48% of cryptogenic species recorded during the repeat survey were also found in the earlier survey.

The 13 non-indigenous organisms found in the repeat survey of Port Taranaki included representatives of 6 major taxonomic groups. The non-indigenous species detected were: (Annelida) *Euchone limnicola*, *Barantolla lepte*; (Bryozoa) *Bugula flabellata*, *Bugula neritina*, *Cryptosula pallasiana*, *Watersipora subtorquata*; (Cnidaria) *Monothecha pulchella*, *Amphisbetia maplestonei*; (Crustacea) *Monocorophium sextonae*; (Mollusca) *Crassostrea gigas*, *Theora lubrica*; (Macroalgae) *Griffithsia crassiuscula*, and *Undaria pinnatifida*. Five of these species - *Euchone limnicola*, *Monothecha pulchella*, *Amphisbetia maplestonei*, *Monocorophium sextonae*, *Undaria pinnatifida* - were not recorded in the earlier baseline

survey of Port Taranaki. In addition, six non-indigenous species that were present in the first survey - *Bugula stolonifera*, *Tricellaria inopinata*, *Watersipora arcuata*, *Eudendrium capillare*, *Polysiphonia sertularioides* and *Halisarca dujardini* – were not found during the repeat survey.

Eleven species recorded in the repeat survey of Taranaki had not been described from New Zealand waters prior to the baseline surveys. One of these was an indigenous species (the hydroid *Amphisbetia maplestoni*). The remaining 10 species do not correspond with existing species descriptions from New Zealand or overseas and may be new to science.

The only species from the second survey included in the New Zealand register of unwanted organisms is the Asian kelp, *Undaria pinnatifida*. This alga is known to have a wide distribution in southern and eastern New Zealand, but this was the first record from Port Taranaki.

Most non-indigenous species located in the Port are likely to have been introduced to New Zealand accidentally by international shipping or spread from other locations in New Zealand (including translocation by shipping). Approximately 61% of non-indigenous species (8 of 13) in the repeat survey are likely to have been introduced in hull fouling assemblages, 8% (1 species) via ballast water and 31% (four species) could have been introduced by either ballast water or hull fouling vectors.

Table 3 Non-indigenous marine species recorded from Port Taranaki during the first (T1) and second (T2) baseline surveys. Likely vectors of introduction are derived mainly from Cranfield *et al.* (1998), where “H” indicates hull fouling and ‘B’ indicates ballast water transport. Novel non-indigenous species not listed in Cranfield *et al.* (1998) or previously encountered in New Zealand are marked as new records (NR). For these, and other species for which information is scarce, we provide dates of first detection rather than probable dates of introduction.

Phylum, Class	Order	Family	Genus and species	T1*	T2*	Probable means of introduction	Date of introduction or detection	Location in Port Taranaki
Annelida								
Polychaeta	Sabellida	Sabellidae	<i>Euchone limnicola</i>	0	1	H or B	Unknown ¹	Breakwaters 1 and 2, Main basin 1 and 2, Moturoa Wharf, Newton King Tanker Terminal No.2
Polychaeta	Scolecida	Capitellidae	<i>Barantolla lepte</i>	1	1	H or B	Unknown ¹	Breakwater 1, Lee Breakwater 1, Newton King Tanker Terminal 2, Yacht Moorings
Bryozoa								
Gymnolaemata	Cheilostomata	Bugulidae	<i>Bugula flabellata</i>	1	1	H	Pre-1949	Blyde Wharf, Breakwater 1 and 2, Moturoa Wharf, Newton King Tanker Terminal 2
Gymnolaemata	Cheilostomata	Bugulidae	<i>Bugula neritina</i>	1	1	H	1949	Blyde Wharf, Breakwater 1 and 2, Lee Breakwater 1, Moturoa Wharf, Newton King Tanker Terminal 2
Gymnolaemata	Cheilostomata	Bugulidae	<i>Bugula stolonifera</i>	1	0	H	1962	Moturoa Wharf
Gymnolaemata	Cheilostomata	Candidae	<i>Tricellaria inopinata</i>	1	0	H	Pre-1964	Lee Breakwater 1
Gymnolaemata	Cheilostomata	Cryptosulidae	<i>Cryptosula pallasiana</i>	1	1	H	1890s	Blyde Wharf, Breakwater 1, Moturoa Wharf, Newton King Tanker Terminal 2
Gymnolaemata	Cheilostomata	Watersiporidae	<i>Watersipora arcuata</i>	1	0	H	Pre-1957	Blyde Wharf, Moturoa Wharf, Newton King Tanker Terminal 2

Table 3 Continued.

Phylum, Class	Order	Family	Genus and species	T1*	T2*	Probable means of introduction	Date of introduction or detection	Location in Port Taranaki
Gymnolaemata	Cheilostomata	Watersiporidae	<i>Watersipora subtorquata</i>	1	1	H or B	Pre-1982	Blyde Wharf, Breakwater 1 and 2, Moturoa Wharf, Newton King Tanker Terminal, Yacht Moorings
Cnidaria								
Hydrozoa	Hydroida	Eudendriidae	<i>Eudendrium capillare (NR)</i>	1	0	H	Nov 2001 ^d	Moturoa Wharf, Newton King Tanker Terminal 2
Hydrozoa	Hydroida	Plumulariidae	<i>Monotheca pulchella</i>	0	1	H	1928	Newton King Tanker Terminal 2
Hydrozoa	Hydroida	Sertulariidae	<i>Amphisbetia maplestonei (NR)</i>	0	1	H	Dec 2004 ^d	Blyde Wharf
Crustacea								
Malacostraca	Amphipoda	Corophiidae	<i>Monocorophium sextonae</i>	0	1	H	Pre-1921	Blyde Wharf, Moturoa Wharf
Mollusca								
Bivalvia	Ostreoida	Ostreidae	<i>Crassostrea gigas</i>	1	1	H	1961	Moturoa Wharf, Newton King Tanker Terminal 2
Bivalvia	Veneroida	Semelidae	<i>Theora lubrica</i>	1	1	B	1971	Blyde Wharf, Breakwater 1 and 2, Lee Breakwater 1, Moturoa Wharf, Newton King Tanker Terminal 2
Macroalgae								
Florideophyceae	Ceramiales	Ceramiaceae	<i>Griffithsia crassiuscula</i>	1	1	H	Pre-1954	Breakwater 2, Moturoa Wharf, Newton King Tanker Terminal 2
Florideophyceae	Ceramiales	Rhodomelaceae	<i>Polysiphonia sertularioides</i>	1	0	H	Pre-1938	Boat ramp, reclamation area
Phaeophyceae	Laminariales	Alariaceae	<i>Undaria pinnatifida</i>	0	1	H or B	Pre-1987	Yacht moorings

Table 3 Continued.

Phylum, Class	Order	Family	Genus and species	T1*	T2*	Probable means of introduction	Date of introduction or detection	Location in Port Taranaki
Porifera								
Demospongiae	Halisarcida	Halisarcidae	<i>Halisarca dujardini</i>	1	0	H or B	Pre-1973	Newton King Tanker Terminal 2

¹ Date of introduction currently unknown but species had been encountered in New Zealand prior to the present survey.

* 1 = Present, 0 = Absent

Table 4 Cryptogenic marine species recorded from Port Taranaki in the first (T1) and second (T2) surveys. “C1”- category 1 cryptogenic species ^a, “C2” - category 2 cryptogenic species ^b.

Major taxonomic groups, Class	Order	Family	Genus and species	Status	T1*	T2*
Annelida						
Polychaeta	Eunicida	Lumbrineridae	<i>Eranno Eranno-A</i>	C2	1	0
Polychaeta	Phyllodocida	Nereididae	<i>Perinereis Perinereis-A</i>	C2	1	1
Polychaeta	Phyllodocida	Phyllodocidae	<i>Eulalia Eulalia-NIWA-2</i>	C2	0	1
Polychaeta	Phyllodocida	Phyllodocidae	<i>Eumida Eumida-B</i>	C2	1	0
Polychaeta	Phyllodocida	Phyllodocidae	<i>Eumida Eumida-C</i>	C2	1	0
Polychaeta	Phyllodocida	Phyllodocidae	<i>Pirakia Pirakia-A</i>	C2	1	0
Polychaeta	Phyllodocida	Syllidae	<i>Autolytus-unknown sp. A</i>	C2	1	1
Polychaeta	Phyllodocida	Syllidae	<i>Eusyllis-unknown Eusyllis-unknown-A</i>	C2	0	1
Polychaeta	Phyllodocida	Syllidae	<i>Eusyllis Eusyllis-A</i>	C2	1	0
Polychaeta	Phyllodocida	Syllidae	<i>Eusyllis Eusyllis-B</i>	C2	1	1
Polychaeta	Phyllodocida	Syllidae	<i>Syllis Syllis-A</i>	C2	1	1
Polychaeta	Phyllodocida	Syllidae	<i>Typosyllis Typosyllis-A</i>	C2	1	0
Polychaeta	Sabellida	Sabellidae	<i>Branchiomma Branchiomma-B</i>	C2	1	0
Polychaeta	Sabellida	Serpulidae	<i>Serpula Serpula-C</i>	C2	0	1
Polychaeta	Scolecida	Capitellidae	<i>Capitella capitata</i>	C1	0	1
Polychaeta	Scolecida	Capitellidae	<i>Heteromastus filiformis</i>	C1	0	1
Polychaeta	Spionida	Spionidae	<i>Paraprionospio Paraprionospio-A [pinnata]</i>	C2	0	1
Polychaeta	Spionida	Spionidae	<i>Scolecopsis Scolecopsis-A</i>	C2	1	0
Polychaeta	Terebellida	Ampharetidae	<i>Amphicteis Amphicteis-A</i>	C2	1	0
Bryozoa						
Gymnolaemata	Cheilostomata	Scrupariidae	<i>Scruparia ambigua</i>	C1	1	0
Chelicerata						
Pycnogonida	Pantopoda	Ammotheidae	<i>Achelia sp. nov. A</i>	C2	1	0
Pycnogonida	Pantopoda	Ammotheidae	<i>Tanystylum sp. B</i>	C2	0	1

Table 4 Continued.

Major taxonomic groups, Class	Order	Family	Genus and species	Status	T1*	T2*
Cnidaria						
Anthozoa	Corallimorpharia	Corallimorphidae	<i>Corynactis australis</i>	C1	1	? ¹
Hydrozoa	Hydroida	Campanulariidae	<i>Clytia hemisphaerica</i>	C1	0	1
Hydrozoa	Hydroida	Plumulariidae	<i>Plumularia setacea</i>	C1	1	1
Crustacea						
Malacostraca	Amphipoda	Aoridae	<i>Aora typica</i>	C1	0	1
Malacostraca	Amphipoda	Dexaminidae	<i>Paradexamine sp. A</i>	C2	0	1
Malacostraca	Amphipoda	Isaeidae	<i>Gammaropsis sp. 1</i>	C2	1	0
Malacostraca	Amphipoda	Leucothoidae	<i>Leucothoe sp. 1</i>	C2	1	1
Malacostraca	Amphipoda	Liljeborgiidae	<i>Liljeborgia sp.</i>	C2	1	0
Malacostraca	Amphipoda	Lysianassidae	<i>Parawaldeckia sp. aff. P. stephensi</i>	C2	0	1
Malacostraca	Brachyura	Grapsidae	<i>Plagusia chabrus</i>	C1	1	0
Malacostraca	Brachyura	Portunidae	<i>Ovalipes elongatus</i>	C1	1	1
Porifera						
Demospongiae	Hadromerida	Suberitidae	<i>Pseudosuberites sulcatus</i>	C1	1	1
Demospongiae	Halichondrida	Halichondriidae	<i>Halichondria new sp. 1</i>	C2	1	1
Demospongiae	Halichondrida	Halichondriidae	<i>Halichondria new sp. 4</i>	C2	0	1
Demospongiae	Haplosclerida	Chalinidae	<i>Haliclona new sp. 4</i>	C2	0	1
Demospongiae	Poecilosclerida	Esperiopsidae	<i>Esperiopsis new sp. 1</i>	C2	1	1
Demospongiae	Poecilosclerida	Hymedesmiidae	<i>Phorbas new sp. 2</i>	C2	1	0
Demospongiae	Poecilosclerida	Mycalidae	<i>Paraesperella new sp. 1 (macrosigma)</i>	C2	1	0
Dinophyta						
Dinophyceae	Gymnodiniales	Gymnodiniaceae	<i>Gymnodinium catenatum</i>	C1	1	1
Urochordata						
Asciacea	Aplousobranchia	Didemnidae	<i>Diplosoma listerianum</i>	C1	1	0
Asciacea	Phlebobranchia	Rhodosomatidae	<i>Corella eumyota</i>	C1	1	1
Asciacea	Stolidobranchia	Botryllinae	<i>Botryllodes leachii</i>	C1	1	0
Asciacea	Stolidobranchia	Pyuridae	<i>Microcosmus australis</i>	C1	1	0
Asciacea	Stolidobranchia	Pyuridae	<i>Microcosmus squamiger</i>	C1	0	1

¹ Not determined at the time of reporting, as specimens of Anthozoa had not been identified.

Table 4 Continued.

Major taxonomic groups, Class	Order	Family	Genus and species	Status	T1*	T2*
Ascidacea	Stolidobranchia	Styelidae	<i>Asterocarpa cerea</i>	C1	1	1
Ascidacea	Stolidobranchia	Styelidae	<i>Styela plicata</i>	C1	1	0

^a Species previously recorded from New Zealand whose identity as either native or non-indigenous is ambiguous.

^b Species that have recently been discovered but for which there is insufficient systematic or biogeographic information to determine whether New Zealand lies within their native range.

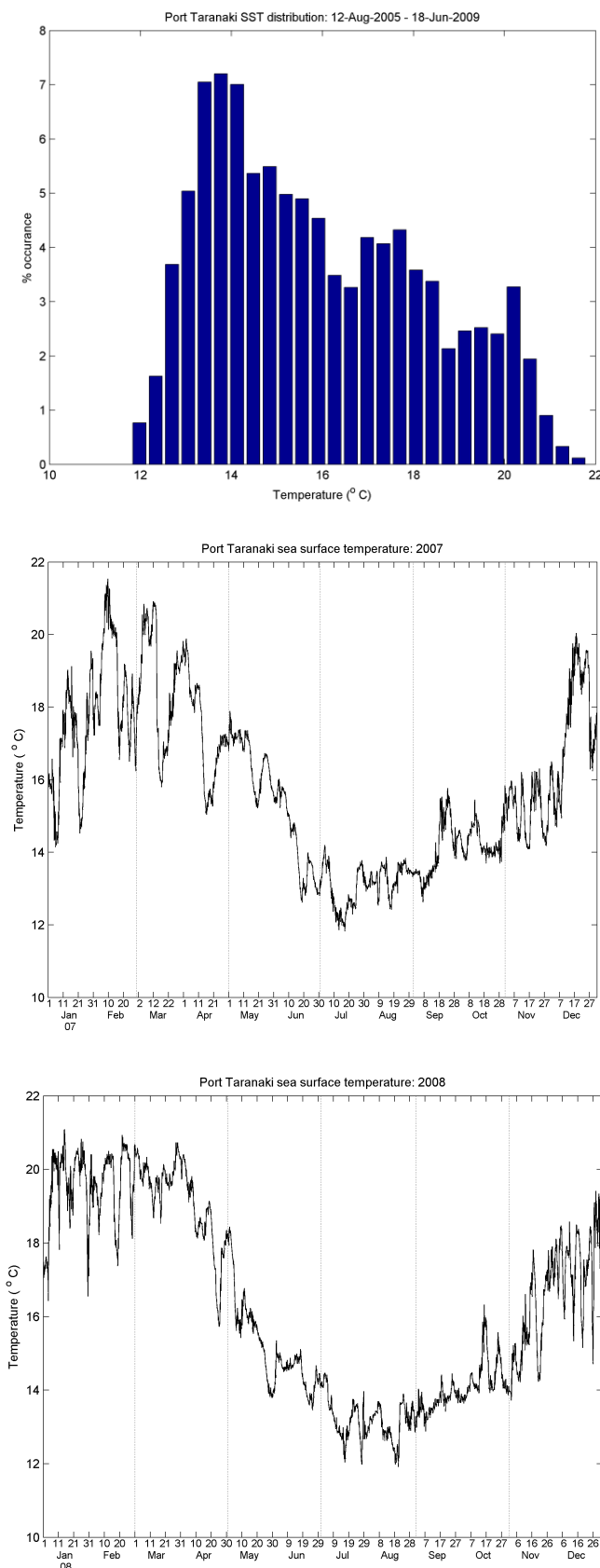
* 1 = Present, 0 = Absent

BIOPHYSICAL CONDITIONS

Data collected in Port Taranaki from August 2005 – June 2009 (Figure 3) show that water temperatures around Port Taranaki ranged from 12 to 22 °C, with the modal temperature being 13-14°C. Time-series plots for 2007 and 2008 show that water temperatures are lowest in July-August and highest in January-February.

Rogers (1995) measured salinity 1 m above the seabed at two locations on the Lee Breakwater (see Figure 1), one in the inside and one on the outside. During the periods 12-28 February and 1-31 March 1994 salinity at the inner site was usually 33 psu but dropped as low as 18 psu for short periods in response to rain events. Salinity at the outer site was slightly higher during the same periods, usually around 35 psu but dropping to 10-17 psu in response to rainfall events. Responses to rainfall were much less common at the outer site, possibly because less runoff reaches this area or because there is less mixing of the lower-density fresh water through the water column at this location. Salinity was also measured at the surface and intermediate depths on two occasions. In summer (February-March), salinities were slightly higher at the surface (by up to 2.5 psu) than at the seabed, presumably because of evaporation.

Figure 3 Upper plot: Frequency distribution of sea-surface temperatures in Port Taranaki during August 2005-June 2009. Middle and lower plots: Daily sea-surface temperatures (°C) during 2007 and 2008, respectively. Data courtesy of Craig Stewart, NIWA (pers. comm., NIWA Coastal SST archive).



HABITAT TYPES WITHIN THE SURVEY AREA

Port Taranaki is located on the central west coast of New Zealand's North Island, servicing the city of New Plymouth (39° 03'S. 174° 02.5'E). The Port was established in 1875. In 1881, work began on a breakwater to provide safe anchorage. The breakwater has been extended four times and reached its present length (1256 m) in 1967 (McComb 2001). Since 1881 the port has grown apace with its province, with increasing export/import and coastal trade, as well as with oil exploration-related trade that has occurred in the Taranaki region since the 1960's.

Port Taranaki is protected from the open sea by two artificial breakwaters, one of which is also a berthing facility (Figure 1). The Port entrance is subject to frequent swell conditions (Henwood 1989) but is easily navigable, with an open roadstead and anchorage in 18-22 m of water. There is no bar. The main Port breakwater has had a large impact on sand transport along the coastline, and sand accumulation has to be controlled by regular dredging (Gibb 1983). The harbour floor consists of a broad, deep trough that merges with the inner continental margin beyond the harbour entrance (Carter *et al.* 1981). Harbour sediments are predominantly anaerobic fine sandy muds or muddy sands (Don 1981, NIWA unpublished data), becoming mixed sand and gravel near the wharves (Carter *et al.* 1981, NIWA unpublished data). Offshore of a line extending between the tip of the Lee Breakwater and the Main Breakwater, the sediment is sand (<30% silt: Black and McComb 2000). Port Taranaki experiences a fairly large tidal range of 1.6 (neap range²) to 3.2 m (spring range). The mean oceanic flow is to the northeast adjacent to the Port. Tidal currents are not significant (they do not exceed 0.5 m s⁻¹ and are typically 0.25 m s⁻¹ or less) and are mainly wind-induced closer inshore (Gibb 1983).

The coastline of the Taranaki region is generally rocky, with sandy beaches present where sediment supply and coastal orientation allow. The seabed consists of rocky reef with patches of sand, often associated with depressions or raised features (McComb 2001). Around Port Taranaki and the Nga Motu Sugar Loaf Marine Protected Area, in contrast, the seabed consists mainly of sand (representing 74% of the area: McComb 2001).

Much of the sediment transported northeast along the coast in shallow depths (<6 m) close to the breakwater is trapped by the harbour, largely on the shoal at the tip of the Main Breakwater (McComb 2001). Sediments in depths of 6-10 m pass the harbour entrance and traverse the shallow reefs to the east of the port. Similar patterns of transport may apply to propagules of animals and plants released to the west of the port.

Types of habitat present in Port Taranaki are listed in Table 5 (and see Figures 1 and 2). Given that much of the available habitat for incoming non-indigenous species is represented by artificial substrata within the port, calculation of habitat area/volume is not feasible within the present project – there are almost certainly no data on numbers of piles, marina pontoons, etc for the whole port and the available habitat area is structurally extremely complex.

Artificial habitats within the Port are described in the following section.

² see the Land Information New Zealand website at <http://www.linz.govt.nz/hydro/tidal-info/tide-tables/tidal-levels/index.aspx>

Table 5 **Types of habitat present in the survey area. See Figure 2 for locations.**

Habitat category	Habitat type	Habitat subdivision	Location
Soft-surface	Sand mud/muddy sand		Outer port area
	Gravelly, muddy sand		Moturoa Wharf, Newton King Tanker Terminal, Blyde Wharf, Lee Breakwater
	Sandy beach		Central and eastern shore of port
Hard-surface	Submerged reef		Shore to west and east of port, Tapuae Marine Reserve, Sugar Loaf Islands Marine Protected Area
	Artificial structures	Commercial vessel berth	Main breakwater, Moturoa Wharf, Newton King Tanker Terminal, Blyde Wharf
		Channel markers	One just outside and two inside the Lee Breakwater (plus others on land)
		Boat ramp	Two in the southeastern corner of port area (Cruising and Underwater Club)
		Marina	Western side of Lee Breakwater, berths for 16 vessels up to 13 m long
		Jetty/Breakwater	Western and eastern sides of port area including Main and Lee Breakwaters
		Moorings	Western side of Lee Breakwater
Pelagic	Water column	Top, middle, bottom.	

IDENTIFICATION OF VECTOR PARAMETERS

Port Taranaki is operated by Port Taranaki Ltd and currently has nine main berths capable of handling a wide diversity of cargoes and vessels with an official maximum draught of 10 m, which may be exceeded by arrangement (www.porttaranaki.co.nz). There were 1560 vessel movements in the port during 2008/2009, representing a 25% decrease on the previous year (Taranaki Regional Council 2009). The inner side of the Main Breakwater terminal primarily handles coastal bulk traders and offshore support vessels, and also caters for the needs of Taranaki's offshore oil and gas operations and providing berths for fishing vessels. Moturoa Wharf is generally used for dry bulk cargoes. Berths on both sides of the Newton King Tanker Terminal handle a wide range of petrochemical products and bulk liquids including crude oils, liquefied petroleum gas and methanol. The newest development at Port Taranaki is the Blyde Terminal, an integrated facility handling containers, general/refrigerated cargoes and catering for vessels that service oil and gas production operations offshore. Berth construction is predominantly concrete deck on concrete or steel piles, although the Main Breakwater is solid concrete.

Outside the Port's operational area, on the lee breakwater, there is a 16-berth marina constructed with steel pontoons and piles. The marina was refurbished in November 2008, including the replacement of 25 piles (source: Taranaki Daily News 5 November 2008). On the southeastern side of the harbour is a 6.5-ha reclamation, with areas currently leased by

retail and marine services. There are two boat ramps between the reclamation and the Lee Breakwater, a jetty on the reclamation, and four jetties on the western side of the breakwater.

Vessels unable to be berthed immediately in the port may anchor outside the port to the west of a line running 197° to the end of the main breakwater, but no closer than 1 nautical mile to any point of land, in approximately 20 m of water. Pilotage is compulsory on vessels over 100 GRT (www.porttaranaki.co.nz).

Sediment transport along the northern Taranaki coast is predominantly northeasterly and the port traps ca 174,000 m³ of clean sands each year, most of which is deposited in a shoal at the tip of the Main Breakwater (McComb 2001). Within the port, maintenance dredging is carried out as required, predominantly in the area encompassed by the Main Breakwater on the west and the tips of the Blyde Wharf and Lee Breakwater on the east. Maintenance dredging usually occurs every two years, with removal of approximately 350,000 m³ in this time. Approximately 75 to 80% of the dredged material is clean fine sand, with the remaining volume consisting of finer materials such as silts. The spoil is deposited in two sites: one in-shore site with sand for beach renourishment, and one off-shore site approximately 2 km north of the breakwater for mud and silt spoil (marked on nautical chart). The inshore spoil site was first used in March 2004, and again in June 2005 after the second port baseline survey (P. Atkinson, Duffill Watts and King Ltd., pers. comm.).

Capital dredging of port areas including the harbour entrance, turning basin and some berths commenced in December 2005 (after the second baseline survey was completed) and completed in 2007. Operating depths in these areas will be increased upon completion of this work. The total volume expected to be dredged is 863,000 m³, all of which will be deposited in the offshore spoil ground. Small volumes were also dredged from June to September 2002 (after the first baseline survey); approximately 1500 m³ were dredged from Blyde No. 2 wharf, around 2,000-3,000 m³ were dredged from the Newton King Tanker Terminal, and several small shallow areas were also dredged around the harbour. All of this material was deposited in the offshore spoil ground (P. Atkinson, pers. comm.).

Imports and exports

The total trade volume for Port Taranaki has declined in recent years, from 5.03 million tonnes in the 2002-2003 financial year to 3.28 million tonnes in 2006-2007 and 3.438 million tonnes in 2007-2008 (Westgate Transport Ltd 2004, Port Taranaki Ltd 2008). This is associated mainly with the decline of the Maui gas field, which accelerated in the 2003-2004 financial year and resulted in large declines in bulk liquid trade tonnages, especially methanol exports (Westgate Transport Ltd 2004). Total cargo volumes increased, however, between 2006 and 2008, due principally to increased activity in the energy sector (Port Taranaki Ltd 2008). Total exports from Port Taranaki thus declined from 5.05 million freight tonnes in the 2001-2002 financial year to 2.68 million freight tonnes in the 2004-2005 financial year, whilst total imports showed a net increase over the same period, from 0.59 to 0.77 million freight tonnes (Westgate Transport Ltd 2005). Continuing growth on the Blyde Terminal (container terminal) resulted in the handling of 51,750 TEU³ in 2004-2005, compared with 48,500 in the previous year and 45,200 in the 2002-2003 year. We used data from Statistics New Zealand to summarise import and export characteristics for Port Taranaki. We summarised total quantities of overseas cargo loaded and unloaded by weight and by value for 2001/2002 to 2004/2005 year (Statistics New Zealand 2006b). Also available from Statistics New Zealand (2006a) was a breakdown of cargo value by country of origin or destination and by commodity for each calendar year. Using these data, we examined the period from 2002 to

³ TEU = twenty foot equivalent unit. This is a standard size of container and a common measure of capacity in the container logistics business.

2005 inclusive (i.e. the period between the first and second baseline surveys). Note that the import and export data presented below only consider cargo being loaded for, or unloaded from, overseas and does not consider domestic cargo. This is, therefore, likely to sum to a lower amount than the total amount of cargo handled by the port.

Imports

Both the weight and value of overseas cargo unloaded at Port Taranaki has increased each year since the 2002 initial baseline survey, with 462,693 tonnes gross weight, valued at \$275 million, being unloaded in the year ended June 2005 (Statistics New Zealand 2006b). This represents an increase in weight of almost 30% and value of almost 53% compared to the year ending June 2002. Overseas cargo unloaded at Port Taranaki accounted for 2-3% by weight and 0.7-1% by value of the total overseas cargo unloaded at New Zealand's seaports.

Port Taranaki imported cargo in 89 different commodity categories between 2002 and 2005 (Statistics New Zealand 2006a). The dominant import commodities by value during this time were fertilisers (25%), mineral fuels, oils and products (17%), dairy produce, bird's eggs, natural honey and other edible animal products (6%) and aluminium and aluminium articles (6%). Fertilisers ranked first each year except in 2005, when they ranked second after dairy. Mineral fuels ranked second or third each year. The ranking of third place overall for dairy is due entirely to a large import in 2005; dairy did not rank in the top 10 in other years (Statistics New Zealand 2006a). Port Taranaki received imports from 89 countries of initial origin between 2002 and 2005 (Statistics New Zealand 2006a). During this time, Port Taranaki imported most of its overseas cargo by value from Australia (25%), the USA (20%), and Saudi Arabia (8%). Australia ranked first and the USA second each year except in 2004 when their ranks were reversed. Saudi Arabia ranked third each year (Statistics New Zealand 2006a).

Exports

In the year ending June 2005, Port Taranaki loaded 1,890,401 tonnes of cargo for export (Statistics New Zealand 2006b). This represented a decline of almost 50% compared to the year ending June 2002, with most of the downturn occurring in the 2003-2004 financial year when the Maui gas field declined. The value of the cargo loaded for export in the year ending June 2005 was similar to the value in the year ending June 2002, but lower than the year ending June 2003. The proportion of the total overseas cargo by weight loaded at New Zealand's seaports loaded by Port Taranaki has dropped from around 15% in 2002 to less than 9% in 2005. However, the proportion by value increased slightly, from 6.8% in 2002 to 7.5% in 2005, although it reached 8.5% in the 2002-2003 financial year.

Port Taranaki exported cargo in 69 different commodity categories between 2002 and 2005 inclusive (Statistics New Zealand 2006a). The dominant commodity categories by value loaded at Port Taranaki for export during this time were dairy produce, bird's eggs, natural honey and other edible animal products (35%), mineral fuels, oils and products (21%), meat and edible meat offal (13%), and confidential items (11%). Dairy produce ranked first and mineral fuels and oils ranked second each year. Confidential items and meat ranked third or fourth each year except in 2002, when meat ranked fifth (Statistics New Zealand 2006a). Log exports have been one of the fastest growing trades in the past five years, and coal, fertilisers and cement volumes also increased strongly in the 2004-2005 year (Westgate Transport Ltd 2005). Port Taranaki loaded cargo for export to 103 countries of final destination⁴ between 2002 and 2005 inclusive (Statistics New Zealand 2006a). During this time, Port Taranaki exported most of its overseas cargo by value to Australia (19%), the USA (16%), Japan

⁴ The country of final destination is not necessarily the country that the ship carrying the commodity goes to immediately after departing from Port Taranaki; it is the final destination of the goods.

(15%), the Republic of Korea (5%) and the People's Republic of China (5%). Australia, the USA and Japan ranked in the top three every year, with Australia ranking first each year except in 2005 when it was outranked by the USA (Statistics New Zealand 2006a).

Shipping movements and ballast discharge patterns in Port Taranaki

Since June 2005, vessels have been required to comply with the Import Health Standard for Ships' Ballast Water from All Countries (<http://www.biosecurity.govt.nz/imports/non-organic/standards/ballastwater.htm>). No ballast water is allowed to be discharged without the express permission of a MAF (Ministry of Agriculture and Forestry) inspector. To allow discharge, vessel masters are responsible for providing the inspector with evidence of: discharging ballast water at sea (200 nm from the nearest land, and at least 200 m depth); or demonstrating that ballast water is fresh (2.5 ppt sodium chloride); or having the ballast water treated by a MAF-approved treatment system.

According to Inglis (2001), a total volume of 1,150,570 m³ of ballast water was discharged in Port Taranaki in 1999, with the largest country-of-origin volumes of 507,895 m³ from Australia, 224,601 m³ from Japan, 210,589 m³ from Hong Kong, and 119,926 m³ unspecified source countries. Shipping from these regions presents an on-going risk of introduction of new non-indigenous species to Port Taranaki.

In 2001-2005, the largest number of vessel arrivals (domestic and international over 100 GRT) in Port Taranaki occurred in the year ending June 2003 (688 arrivals), while the smallest number of arrivals occurred in the year ending June 2005 (562 arrivals, Westgate Transport Ltd 2005).

To gain a more detailed understanding of international and domestic vessel movements to and from Port Taranaki between 2002 and 2005 inclusive, we analysed a database of vessel movements generated and updated by Lloyds Marine Intelligence Unit, called 'SeaSearcher.com'. Drawing on real-time information from a network of Lloyd's agents and other sources around the world, the database contains arrival and departure details of all ocean going merchant vessels larger than 99 gross tonnes for all of the ports in the baseline surveys. The database does not include movement records for domestic or international ferries plying definitive scheduled routes, small domestic fishing vessels or recreational vessels. Cruise ships, coastal cargo vessels and all other vessels over 99 gross tonnes excluding scheduled ferry services are included in the database. The database, therefore, gives a good indication of the movements of international and domestic vessels involved in trade. The results of the search are summarised below (further details are available in Inglis *et al.* 2006a).

International vessel movements

Based on an analysis of the LMIU 'Seasearcher.com' database there were 612 vessel arrivals to Port Taranaki from overseas ports between 2002 and 2005 inclusive. These arrived from 40 different countries represented by most regions of the world. The greatest number of overseas arrivals during this period came from the following areas: Australia (230), Pacific Islands (127), Japan (79), and the northwest Pacific (68). The previous ports of call for three of the international arrivals were not stated in the database. Vessels arriving from Australia came mostly from ports in Queensland (138 arrivals), New South Wales (33), and Victoria (32). The major vessel types arriving from overseas at Port Taranaki were tankers (218 arrivals), LPG/LNG carriers (138 arrivals), and container ships and ro/ro vessels (134 arrivals).

According to the LMIU 'Seasearcher.com' database, during the same period 818 vessels departed from Port Taranaki to 28 different countries, also represented by most regions of the world (but not to the European Atlantic coast). The greatest number of departures for overseas

went to Australian ports as their next port of call (379 movements), followed by east Asian seas (154), Japan (108), the northwest Pacific (84) and the Pacific Islands (74). The major vessel types departing to overseas ports from Port Taranaki were tankers (312 movements), container ships and ro/ro (250), LPG/LNG carriers (117) and general cargo vessels (75).

Domestic vessel movements

The LMIU database contained movement records for 1,123 vessel arrivals to Port Taranaki from New Zealand ports between 2002 and 2005 inclusive. These arrived from 16 different ports in both the North and South Islands. The greatest number of domestic arrivals during this period came from Lyttelton (270 arrivals), Nelson (162 arrivals), Dunedin (142 arrivals), and Wellington (131 arrivals). The dominant vessel types arriving from New Zealand ports were LPG/LNG carriers (240 arrivals), container ships and ro/ro's (234), tankers (207), general cargo vessels (206), and bulk / cement carriers (187 arrivals).

During the same period, the LMIU database contained movement records for 903 vessel departures from Port Taranaki to 16 New Zealand ports in both the North and South Islands. The most domestic movements departed Port Taranaki for Lyttelton (216 movements), Wellington (99), Taranaki (i.e. closed-loop trips; 79 departures), Napier (76) and Dunedin and Nelson (70 each). LPG/LNG carriers dominated the vessel types leaving Port Taranaki on domestic voyages (260 movements), followed by bulk / cement carriers (196 movements), general cargo vessels (170 movements), tankers (113), and container ships and ro/ro's (109 movements). In 2000, there were 15 registered fishing vessels in Port Taranaki (Sinner *et al* 2000).

Possible vectors for the introduction of non-indigenous species

The non-indigenous species located in Port Taranaki are thought to have arrived in New Zealand via international shipping. They may have reached the port directly from overseas or through domestic spread (natural and/or anthropogenic) from other New Zealand ports. Table 3 indicates the possible vectors for the introduction of each non-indigenous species recorded from Port Taranaki during the baseline port surveys. Likely vectors of introduction are largely derived from Cranfield *et al.* (1998) and expert opinion. They suggest that only one of the 19 non-indigenous species (5%) probably arrived via ballast water, 13 species (68 %) were most likely to be associated with hull fouling, and five species (27 %) could have arrived via either of these mechanisms. Other potential vectors include the domestic and international movement of organisms in dredge hoppers and domestic relocation of fouled maritime equipment (e.g. ropes, pontoons, buoys, etc).

Assessment of the risk of new introductions to the port

Many of the non-indigenous species introduced to New Zealand ports by shipping do not establish self-sustaining local populations. Those that do often come from coastlines that have similar marine environments to New Zealand. For example, approximately 80% of the marine non-indigenous species known to be present within New Zealand are native to temperate coastlines of Europe, the northwest Pacific, and southern Australia (Cranfield *et al.* 1998).

Between 2002 and 2005, there were 612 vessel arrivals from overseas to Port Taranaki recorded in the LMIU database. The greatest number of these came from Queensland (138) and other parts of Australia (92), followed by the Pacific Islands (127), Japan (79), northwest Pacific (68), and east Asian seas (29). Approximately half of this trade is with ports from other temperate regions that have coastal environments similar to New Zealand's (for example, southern Australia, Japan and the northwest Pacific). Vessels arriving from tropical

areas with coastal environments strongly dissimilar to New Zealand's (e.g. the Pacific Islands and east Asian seas) may present less of a risk.

Bulk carriers and tankers that arrive empty carry the largest volumes of ballast water. In Port Taranaki, these came predominantly from Australia (114 visits), the Pacific Islands (115), Japan (73) and the northwest Pacific (66). Port Taranaki has a high trade volume of bulk cargoes relative to other ports in New Zealand, ranking second largest with regard to export volume (freight tonnes handled, Statistics New Zealand 2004). This is reflected in the relatively high volume of ballast that is discharged in Port Taranaki (see above).

Smaller, slower moving vessels, such as barges and fishing boats, tend to carry a greater density of fouling organisms than faster cargo vessels. There were only 12 visits to Port Taranaki by these vessels recorded in the 'Seasearcher.com' database, with the greatest number (6) arriving from Australia.

Shipping from southern Australia, Japan and the northwest Pacific (predominantly China, Korea, Russia and Taiwan) present the greatest risk of introducing new non-indigenous species to Port Taranaki. These countries have similar temperate marine environments to New Zealand, and are among the largest sources of vessel visits to Taranaki, including visits by vessel types that carry large volumes of ballast water. Because of the relatively short transit time, shipping originating in southern Australia (particularly Victoria and Tasmania) carries, perhaps, the greatest overall risk. Furthermore, six of the eight marine pests on the New Zealand Register of Unwanted Organisms are already present there (*Carcinus maenas*, *Asterias amurens*, *Sabella spallanzanii*, *Caulerpa taxifolia*, *Styela clava* and *Undaria pinnatifida*). The native range of the other two species – *Eriocheir sinensis* and *Potamocorbula amurens* – is the northwestern Pacific, including China and Japan.

Assessment of translocation risk for introduced species found in the port

Between 2002 and 2005, vessels departing from Port Taranaki travelled to 16 ports throughout New Zealand. Lyttelton, Wellington, Napier, Dunedin and Nelson were the next ports of call for most domestic vessel movements from Taranaki. Although many of the non-indigenous species found in the re-survey of Port Taranaki have been recorded in other locations throughout New Zealand, they were not detected in all of the other ports surveyed. There is, therefore, a risk that species established in Port Taranaki could be spread to other New Zealand locations.

Two species present in Port Taranaki are of note for other locations in New Zealand. The invasive alga *Undaria pinnatifida* is on the New Zealand Register of Unwanted Species. It has been present in New Zealand since at least 1987 and has spread through shipping and other vectors to 13 of the 16 ports and marinas surveyed during the baseline surveys (the exceptions being Opuā, Whangarei Port and marina and Gulf Harbour marina). Until recently it was absent from Port Taranaki and the Port of Tauranga. Apart from Port Taranaki, all of the known infestations are currently on the east coast of New Zealand and the top of the South Island (Nelson, Picton). The second baseline biological survey of Port Taranaki (Inglis *et al.* 2008) provided the first record of *U. pinnatifida* on the west coast of New Zealand. Its presence in Port Taranaki could provide a new source location for spread of the alga to other west coast locations, including sensitive areas such as the nearby Sugar Loaf Islands Marine Protected Area. According to the 'Seasearcher.com' database Port Taranaki has regular shipping connections with the ports of Westport (44 vessels departing Taranaki in 2002-2005), Onehunga (23 vessels) and, to a lesser extent, Greymouth (8 vessels). The large densities of *U. pinnatifida* within the marina at Port Taranaki suggest that it may have been transported into the port by fouled smaller vessels (e.g. coastal fishing vessels and

recreational craft). Although an attempt has been made to eradicate the local population of *U. pinnatifida* in Port Taranaki, there is a continuing risk that it could be spread to other locations and reintroduced to the port from established populations in Lyttelton, Wellington, Napier, Dunedin and Nelson, which have frequent shipping links with the port. The risk of translocation of *U. pinnatifida* is greatest for slow-moving vessels, such as yachts and barges, and vessels that have long residence times in port.

Cysts of the dinoflagellate *Gymnodinium catenatum* were also reported from Port Taranaki. *G. catenatum* produces saxitoxins and gonyautoxins that can cause Paralytic Shellfish Poisoning (PSP) and it is, therefore, a threat to shellfish aquaculture. A bloom of *G. catenatum* between May 2000 and February 2001 contaminated shellfish with PSP toxins around the coast of the North Island, but there have been few PSP events recorded from the Marlborough Sounds and further south in New Zealand (New Zealand Food Safety Authority 2003). There is potential, therefore, for shipping and other vectors to spread *G. catenatum* to shellfish producing and harvesting areas where it has not yet been recorded. In a risk profiling study of marine pests in Australia, *G. catenatum* was considered to have high invasion potential and to be one of the ten most damaging species based on actual (or potential) human health, economic and environmental impacts (invasion potential, Hayes *et al.* 2004).

Several other non-indigenous species that are present in Port Taranaki have relatively restricted distributions around New Zealand and could be spread to other ports and marinas. These include the polychaete worms *Euchone limnicola* and *Barantolla lepte*, the Pacific oyster *Crassostrea gigas*, and the hydroids *Monothecha pulchella* and *Amphisbetia maplestonei*. Only limited information is available about potential impacts of the hydroid species. Based on current information the impacts of *Monothecha pulchella* are likely to be no more than minor. However, whilst the impacts of *Amphisbetia maplestonei* in New Zealand are unknown, a related hydroid, the native species *A. bispinosa*, commonly fouls the shells of cultured Greenshell mussels (*Perna canaliculus*). Heavy growths of *A. bispinosa* on marine farms in the Coromandel and Firth of Thames have increased the costs of cleaning and harvesting and may negatively affect mussel production. It is possible that *A. maplestonei* could have similar impacts, although this has not yet been recorded. The other three species can potentially modify benthic habitats, where they occur in large densities. *C. gigas*, in particular, has caused significant changes to natural ecosystems where it has invaded native environments in New Zealand and overseas (Wolff and Reise 2002). Hayes *et al.* (2004) ranked its impact potential as fifth out of 53 potential pest species in Australian waters. Although *C. gigas* is now widespread in northern New Zealand, it is still absent from southern ports where it could potentially survive.

LOCAL CONSTRAINING FACTORS ON SURVEILLANCE SUCCESS

Local factors likely to constrain sampling, including those representing hazards to field team members, are listed in Table 6, together with management actions to mitigate them.

Table 6 Hazard analysis for biophysical conditions of surveillance locations.

Hazard/Constraining Factor	Effect at Surveillance Location	Present (Y, N or intermittent (I))	Management actions
Patterns of water movement in and around the port	Water residence time for port not known but propagules, like suspended sediments, may become entrapped in the port area or transported eastwards	Y	Dispersal of sampling effort incorporates areas east of the port that larvae may reach under predominant wind and current conditions.
Turbidity	Turbidity low in port (Secchi disk depth 3.2-6.4 m recorded during baseline survey), but intermittently high in response to rainfall	I	High variability in detection probability of diver searches
Predominant wind directions are westerly or southeasterly (NIWA climate database records from New Plymouth Airport)	Boat handling can be difficult in exposed areas during high winds, but the port is sheltered from the predominant wind directions. In summer onshore sea breeze in the afternoon may constrain sampling work from boats	I	Dispersal of sampling effort incorporates areas east of the port that larvae may reach under predominant wind and current conditions.
Tidal currents are not strong (they do not exceed 0.5 m s^{-1} and are typically 0.25 m s^{-1} or less: Gibb 1983). A NE current of up to 1.5kt runs after prolonged SW winds, and a similar W current after prolonged E winds (see www.porttaranaki.co.nz/index.htm)	No particular restrictions on sampling activity	I	No particular actions required
Swell and inshore waves	Taranaki coast experiences large oceanic swells, predominantly SW and most often in autumn or winter, with breakers along the shore		May restrict sampling operations outside the port, particularly in shallower areas. May influence areas inside port too.
Spring-neap tidal cycle	Spring high tides in Taranaki occur mid-late morning, with associated maximal current speeds and suboptimal conditions for shore searches	I	Surveys are timed to avoid spring tides
High rainfall can occur throughout the year	High turbidity and possible risk of coliform contamination from Waiwhakaiho River and Te Henui Stream	I	Sampling (particularly diving) may be postponed after very heavy rain because of poor visibility
Temperature	Minimum water temperatures in winter are ca 12°C	Y	Diving and other sampling still possible providing divers are adequately equipped (dry suits)
Dangerous animals	Fur seals breed on the Sugar Loaf Islands.	I	Not generally a problem within the Port but should be taken into consideration during diving

Table 6 Continued.

Hazard/Constraining Factor	Effect at Surveillance Location	Present (Y, N or intermittent (I))	Management actions
Vessel traffic	Periodic but predictable for main port, frequent and unpredictable at fishing-boat and recreational berths	Y	Sampling of main port can be planned through consultation of Port Taranaki shipping movement website and communication with shipping manager at the start of each survey and during survey work to monitor (common) changes to schedules. The marina company will also be consulted and traps, etc. deployed to ensure they do not impede vessel movements.
Dredging and construction activities	Regular maintenance dredging and periodic construction activity on the port wharves and marina berths	I	May require that parts of the wharves are not sampled at times when construction is in progress, or that channels sites are not sampled with the sled when dredger is on station, but these periods are usually of limited duration. When dredger is working, sampling vessels need to keep clear and not impede its trips out to the spoil ground.
Cables, pipelines and other hazards to navigation	The navigational chart for the port area does not show any cables or pipelines. There is an outfall east of the Waiwhakaiho River mouth.	Y	Boat handlers to be aware of location of cables and sledding and trapping must avoid these areas.
Pollution (sewer outfall)	No outfalls within the harbour. On open coast high river flows may cause coliform contamination from livestock.	I	Diving and other work may have to be postponed – Regional Council will be consulted for advice
Diving related (entanglement)	Areas that are publicly accessible are heavily used by anglers and fishing line presents an entanglement hazard. Wild oysters are a hazard to exposed skin and diving equipment.	Y	Divers carry knives or shears at all times and boat support with standby diver is always present. Divers also wear gloves to avoid oyster cuts.

PORT SECURITY ISSUES

Port Taranaki is required to comply with the International Ship and Port Facility Security Code that came into effect on 1 July 2004, and has introduced policies and procedures to control access to the port's secure areas. Target-species surveillance operations are designed to comply with all security requirements of the port. The field team will meet with the Tanker Terminal Manager at the start of the survey for a safety induction, to address specific safety issues and discuss communications protocols.

Selection of sampling methods for target species

HABITAT ASSOCIATIONS AND LIFE HISTORIES OF THE TARGET ORGANISMS

Information on the habitat associations and life histories of the primary target species is collated in Appendix 2.

SELECTING LIFE STAGES TO TARGET

It has been agreed with MAFBNZ that sampling for planktonic lifestages of target organisms is not currently a feasible option and is not included in the scope of the present contract (*Contract Specification Addendum* page 52). Identification of larval stages of target species is generally considerably more difficult than identification of adults. While molecular probes are available for some non-indigenous species, problems of sampling remain unresolved. These include the volume of water to be sampled, the location of samples and the question of how, if the probe gives a positive result, the location (and size) of the source population can be identified. At present, therefore, although these methods may potentially provide presence/absence information on target species, they are of little practical use for managing any incursions detected. A critical part of operationalising molecular probes for field based sampling is testing their specificity for the target organism. That is, although a gene sequence may have been identified for a pest species, we cannot use it reliably in field surveys until its sensitivity to other, related native species has been tested.

SAMPLING METHODS

In comparison to surveys for agricultural pests, survey methods for invasive marine organisms are still relatively undeveloped. Most studies of marine pests have used conventional ecological survey techniques, such as baited traps (Veldhuizen and Stanish 1999, Yamada *et al.* 2001, Thresher *et al.* 2003), diver surveys (Currie *et al.* 2000), and benthic grab (Carlton *et al.* 1990) or sled samples (Parry and Cohen 2001). These methods are relatively non-specific and can be labour-intensive, limiting the number of locations that can be searched effectively. A documented process for the selection of sampling methods and allocation of sampling effort for the target species was developed at the start of the previous phase of the programme (Inglis *et al.* 2006b) and included information on the biology and behaviour of the target organisms and sampling methods used for the same or similar species in other parts of their range. Sensitivity (referred to in previous reports as the “efficiency” of the survey method), cost-effectiveness, feasibility and consistency with safe field-working practice were also evaluated in selecting methods, although in most cases the actual sensitivity of the method has not been quantified.

To decide on appropriate sampling methods for each of the target species, we reviewed published information on methods that had been used previously to sample each species and asked experts working on the species in its native or introduced range to comment on the utility of the methods we had proposed for surveillance monitoring (see Appendix 3). The criteria used to select survey methods were:

- effectiveness at capturing the target species when it is present,
- cost and ease of sampling,
- minimal impact on native marine environments and species, and
- safety of field personnel, the general public and property.

Since the purpose of the surveillance programme is detection, not enumeration, techniques in which the presence or absence of the target species could be determined rapidly within a sample were selected, allowing a comparatively large number of locations to be sampled on each survey. Baited box traps were used to sample adult crabs (i.e. *Carcinus maenas* and

Eriocheir sinensis) and Whayman-Holdsworth starfish traps were used to catch asteroids and other large benthic scavengers. Baited traps do not sample juvenile and subadult *E. sinensis* effectively because these life stages have a largely herbivorous diet. They were therefore sampled with artificial shelters (“crab condos”) designed for surveys of *E. sinensis* in San Francisco Bay. An Ocklemann epibenthic sled was used to sample soft sediment habitats for *Potamocorbula amurensis*, *Sabella spallanzanii*, *Asterias amurensis* and *Caulerpa taxifolia*. Divers searched for *S. spallanzanii*, *C. maenas*, *A. amurensis* and *Styela clava* around piles, floating pontoons and other artificial structures in port and marina environments, and on intertidal and shallow subtidal reefs that were identified as high risk by the dispersal modelling. Timed visual searches for target species were made of intertidal rocky and sandy shorelines.

We considered that the methods selected for the previous phase of this programme (see Table 7) were successful and appropriate, and proposed that they be used in the present study, subject to discussion and approval from MAFBNZ. This was accepted by MAFBNZ, as stated in the *Contract Specification Addendum* (page 51).

The minimum size of organism retained by the various trapping and sledding methods in governed by the size of mesh used. In the case of the crab (box) traps the netting covering the trap has a 1.3-cm mesh, that on the starfish traps is 2.6 cm and the bag inside the epibenthic sled has a 2-mm mesh.

Table 7 Summary of proposed sampling methods, target organisms and selection factors. Note that *Didemnum* sp. was removed from the list of target species by MAFBNZ in December 2008.

Method	Target species	Habitat	Spatial coverage	Effectiveness	Cost effectiveness	Feasibility	Previous surveillance in NZ	Previous surveillance overseas
Epibenthic sled tows	<i>Asterias amurensis</i> <i>Caulerpa taxifolia</i> <i>Didemnum</i> sp. <i>Eudistoma elongatum</i> <i>Musculista senhousia</i> <i>Potamocorbula amurensis</i> <i>Sabella spallanzanii</i>	Subtidal soft sediments Particular focus on known shellfish beds (for <i>Asterias</i>) and areas next to public access (e.g. wharves, boat ramps, marinas, etc. <i>Caulerpa</i> , <i>Sabella</i>)	Narrow width but 50 m tow length and high replication (100+ per location) enables a reasonably large area to be sampled (ca 2500m ² per location)	Reliable sample collection including asteroids, infaunal and epifaunal bivalves and polychaetes and macroalgae	Processing of sled contents can be time consuming	Feasible on all soft-sediment habitats under reasonable weather conditions. Can be limited by the presence of large amounts of benthic macroalgae or soft mud that fill mouth of sled	Yes	Yes
Starfish traps	<i>Asterias amurensis</i> and other motile scavengers	Adjacent to wharf pilings and other artificial habitats	Sampled area is dependent on dispersion of bait odour. High replication possible.	Has been used effectively to monitor <i>A. amurensis</i> in Australia and benthic predators around marine farms in NZ	Quick to deploy and recover, so high replication possible	Most locations and weather conditions	Yes	Yes (Martin and Proctor 2000)
Box (crab) traps	<i>Carcinus maenas</i> <i>Eriocheir sinensis</i> <i>Charybdis japonica</i>	Intertidal and shallow subtidal rocky shores, breakwalls and saltmarsh Particular focus on habitats with complex physical structure (e.g. mussel beds, seagrass beds)	Sampled area is dependent on dispersion of bait odour. High replication possible.	Effectively sample other species of crabs (<i>Ovalipes</i> , <i>Macrophthalmus</i> , <i>Charybdis</i>)	Quick to deploy and recover, so high replication possible	Most locations and weather conditions	Yes	Yes (Hewitt and Martin 2001, May and Brown, 2001 Thresher <i>et al.</i> 2003, Yamada <i>et al.</i> 2004)

Table 7 Continued.

Method	Target species	Habitat	Spatial coverage	Effectiveness	Cost effectiveness	Feasibility	Previous surveillance in NZ	Previous surveillance overseas
Crab condos	<i>Eriocheir sinensis</i> <i>Carcinus maenas</i> <i>Charybdis japonica</i>	Intertidal and shallow subtidal banks of rivers. Particular focus on brackish water habitats with complex physical structure (e.g. saltmarsh or fringing vegetation)	High replication possible. Availability of suitable estuarine habitat may limit deployment	Effectively sample other species of crabs (<i>Helice</i> , <i>Macrophthalmus</i>). Higher rates of detection of crabs than baited traps in muddy river banks (Veldhuizen 2000).	Quick to deploy and recover, so high replication possible	High – access problems at some sites (shallow water, deep mud, private land)	Yes	Yes (Veldhuizen 2000)
Shoreline searches	<i>Eriocheir sinensis</i> <i>Carcinus maenas</i> <i>Caulerpa taxifolia</i> <i>Charybdis japonica</i> <i>Didemnum</i> sp. <i>Eudistoma elongatum</i> <i>Grateloupia turuturu</i> <i>Styela clava</i>	Sloping sandy shorelines, intertidal rocky reefs and areas where drift material is likely to accumulate. Prevailing winds on preceding days are a useful guide to where material may accumulate	Wide – can cover long stretches of intertidal habitat quickly	Used effectively in delimitation studies of <i>Styela</i>	High	High – access to intertidal areas may be limiting	Yes	Yes
Diver searches	<i>Carcinus maenas</i> <i>Asterias amurensis</i> <i>Didemnum</i> sp. <i>Eudistoma elongatum</i> <i>Grateloupia turuturu</i> <i>Sabella spallanzanii</i> <i>Styela clava</i>	Wharf piles, marina piles and pontoons and other artificial structures, intertidal and shallow subtidal reefs.	Good – large numbers of piles or lengths of hard substratum can be searched in detail	Dependent on water clarity and level of biofouling	Cost effective in reasonable water clarity, can be time-consuming under poor conditions	Feasibility dependent on water currents, weather, water clarity and safety issues for divers	Yes	Yes

SURVEILLANCE FOR NON-TARGET SPECIES

The secondary objectives of the programme are:

- To detect incursions of non-target non-indigenous or cryptogenic species not previously recorded in New Zealand
- To detect incursions of established non-indigenous or cryptogenic species that are exhibiting invasive characteristics (i.e. range extensions of established organisms).

This objective will be addressed opportunistically. This is inevitable given the taxonomic range of potential new non-indigenous or cryptogenic species and of established non-indigenous or cryptogenic species that might exhibit invasive characteristics. The diversity of specialist taxonomic skills required to identify this range of taxa is unlikely to be present in any one field team, and collection of all potential material for laboratory identification is beyond the scope of this project. In the previous phase of the targeted surveillance programme we identified a suite of non-target, non-indigenous species known to occur in New Zealand (some of which are now included in the list of additional target species) that were consistently recorded when encountered during surveys (see Inglis *et al.* 2006b and Morrissey *et al.* 2007). In the present phase, we will retain this suite of species, to be recorded along with the primary target species whenever encountered.

These records will be assessed against the criteria of Chapman and Carlton (1991):

- Sudden appearance in the surveillance location⁵
- Has the species spread subsequently
- Association with, or dependency on, non natural dispersal mechanisms
- Strong association with artificial substrate⁶
- Tendency towards monoculture or high local abundance
- Restricted distribution (e.g. only near a likely point of pest introduction by human activities)
- Rapid increase in abundance⁵
- Disjunct global distribution
- Are natural dispersal mechanisms inadequate to reach New Zealand
- Genetic or morphological isolation from most similar species distribution elsewhere in the world.

Note that any one of these triggers may immediately indicate an unknown invasive species, however others, such as abundance or distribution, may only become apparent after further surveillance.

TIMING OF SAMPLING ACTIVITY

In the absence of suitable methods of sampling planktonic life stages (see above), sampling is done biannually, in summer (November to March) and winter (May to September) at each location to account for possible changes in abundance of adults of the target species. Adults of all of the primary target species are perennial and likely to be present throughout the year. Timing of sampling is constrained by the need to sample all eight locations (ten during the first round of sampling, when Picton and Opua are also sampled) within each summer and winter period (each survey takes at least a week, with a week in between surveys to allow equipment to be sent on to the next location).

⁵ assumes prior knowledge of taxa in surveillance location.

⁶ assumes comparable sampling of artificial and natural substrata has occurred.

DETERMINATION OF SAMPLING EFFORT

MAFBNZ have specified, in consultation with NIWA (as set out in the *Contract Specification Addendum*), that the total sampling effort in each harbour and survey (i.e. total number of sites surveyed and samples taken) will be governed by a fixed cost, since at the time the tender was let, criteria were not specified for the size of infestation to be detected or the desired confidence of detection, both of which are necessary to estimate a statistically robust sample size (Carter 1989, Binns *et al.* 2001). The budget allowed a field team of six people (operating from two vessels) to work in each harbour for up to six days using the six different survey methods. During the first surveillance programme (2002-2004) we established the average time taken to obtain samples with each method and the number of sites that could be surveyed in the allotted time. This varied somewhat among harbours according to the size of the harbour and the availability of suitable habitat for the target species. The initial estimates of sample time were then used to set targets for the numbers of sites sampled with each technique in subsequent surveys. The allocation of effort among the different survey techniques (Table 8) reflected the relative abundance of each type of habitat in the harbour. For example, most sample effort was allocated to sledging (soft-sediment habitats) and crab trapping (structurally complex habitats including wharf structures and subtidal rocky habitats) because these habitats typically covered the largest part of the survey area.

Table 8 Allocation of sampling effort among the survey techniques proposed.

Sampling method	Target number
Crab condo lines ¹	8
Crab (box) trap lines ²	60
Starfish trap lines ³	20
Epibenthic sled tows	100
Diver searches	30
Shore searches	25

¹ 3 traps per line

² 3 traps per line

³ 2 traps per line

The numbers of samples taken in each harbour during the field surveys in the 2002-2004 sampling programme were similar to those used in the present programme. They generally provided low probabilities of detection of manageable-sized incursions (i.e. <1.5 ha.) for most of the target species (see Inglis *et al.* 2006b for a description of the methods for estimating probabilities of detection). The chance of a sizeable incursion being missed because of statistically low sample numbers, sparse distribution of an incursion and the chance placement of survey locations is amply illustrated by Waitemata Harbour, where less than 0.6 % of the total linear distance of the artificial structures could be sampled on each survey. As a result, even a relatively large infestation in Waitemata Harbour over a combined linear distance of 1 km could be expected to be found in only one out of every 10 surveys (i.e. probability of detection = 0.11). Such infestations are not usually distributed contiguously, but can be comprised of many small clusters of abundance distributed over a large area. In these circumstances (i.e. statistically low sample number and sparsely distributed incursion) a sizeable incursion can be missed by the chance placement of survey locations.

As stated in the *Contract Specification Addendum*, the elements of the survey design required to set realistic targets for the desired level of confidence and the minimum detectable incursion size may be explored and determined between MAFBNZ and NIWA when available research provides sufficient information on which to base these determinations. The surveillance survey design may then be varied to take account of this new information. It is expected that opportunities for continued improvement will be explored and implemented

where appropriate and agreed to during the course of this contract. Determining an appropriate level of sampling requires explicit consideration of the following:

- (1) the minimum size of incursion that is required to be detected by the survey (the “design prevalence”);
- (2) how confident the manager wishes to be that an incursion of that size or greater will be detected (the “confidence of detection”), since absolute confidence is not possible (Cannon 2002; Cameron 2002; Venette *et al.* 2002; Inglis *et al.* 2006b; Hayes *et al.* 2005);
- (3) intuitively, it seems obvious that smaller incursions might be contained more easily than larger ones, but there is little guidance in the literature about how big (or small) such a target should be;
- (4) resources available.

SPATIAL ALLOCATION OF SAMPLING EFFORT

Allocation of sampling effort in the present programme follows the strategy used in previous programmes (Inglis *et al.* 2006b, Morrissey *et al.* 2007). Survey plans were developed for each sampling method and harbour based on the known distribution of habitat for the target species and outputs from the hydrodynamic modelling. We originally anticipated combining the predictive habitat models with the outputs from the plume dispersal simulations in each harbour to identify risk zones in each harbour (the habitat and hydrodynamic modelling are described by Inglis *et al.* 2006b). The area of each habitat in each risk zone (the “search area”) could then be determined and detection limits estimated quantitatively for each zone.

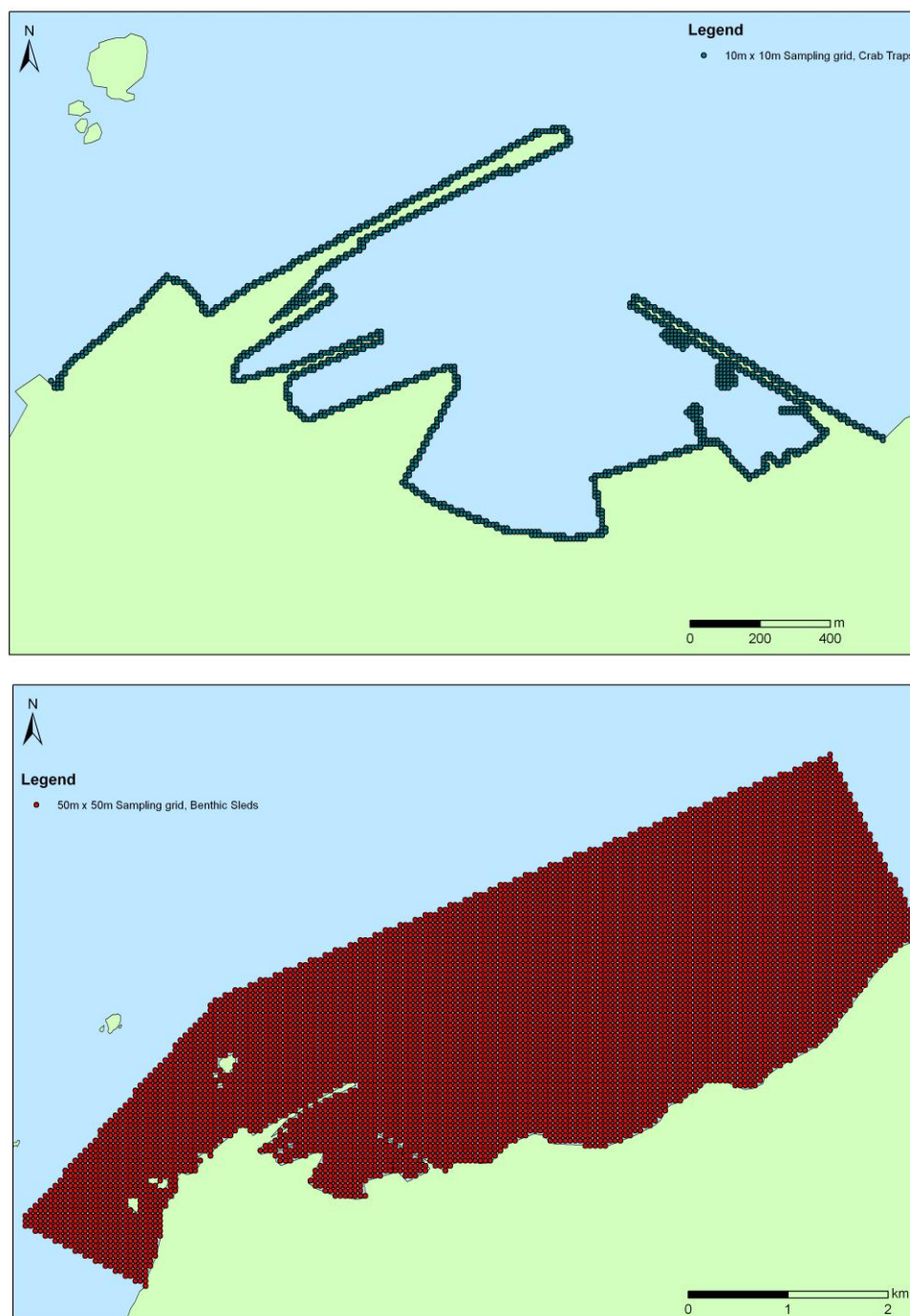
However, the major constraint to achieving this was the limited availability of spatially explicit data on the key environmental variables needed to project the predicted habitat distributions in each harbour. Instead, we allocated sampling effort based predominantly on the results of the hydrodynamic modelling and our existing knowledge of the distribution of habitats in each harbour, with highest priority given to suitable habitat for the target species within the predicted dispersion plume. Hydrodynamic modelling was not available for Port Taranaki because it was only added to the list of ports in August 2009 and resources were lacking. Consequently, sampling effort in this port was allocated on the basis of habitat distribution. Each harbour was subdivided into large strata (3-4 per harbour) that reflected broad environmental gradients (e.g. head/entrance of the harbour) and the concentrations of particles simulated in the hydrodynamic modelling. Generally, ~60% of locations surveyed were allocated to the stratum where moderate to high weighted mean concentrations of simulated particles were predicted, with the remainder distributed among the remaining strata.

Because marine organisms are typically aggregated in their spatial distribution, they tend to be absent from, or in comparatively low abundance at most locations and in large densities in relatively few places (Gray 2002). This pattern is even more extreme for the small founder populations of introduced species, which, at least initially, are likely to be absent from most areas and to occur in aggregations at relatively few locations (Gaston 1994). For example, during the initial stages of its invasion of Port Phillip Bay, Australia, the seastar *Asterias amurensis* was found at only two out of more 70 locations surveyed in the bay (Garnham 1998). This pattern of distribution – locally abundant, but geographically restricted founder populations – suggests that, in most instances, the probability of detection within locations where the species is present is likely to be greater than its expected rarity among locations. Since eradication and control efforts are likely to be most successful when infestations are relatively localised, surveys that optimise the number of locations surveyed will stand the best chance of detecting founding populations with aggregated distributions (Green and Young 1993). Thus, given limited resources, surveying a relatively large number of discrete locations using rapid sampling techniques is likely to be more effective than intensive searches of a few

key locations (although there will be a point at which the survey sensitivity is compromised by under-sampling at each location). This basic assumption - the need to sample a large number of survey locations in each harbour - formed the foundation for our choice of survey methods.

Within each harbour, a grid is overlain on the areas to be sampled in GIS. Grid cells measured 10 x 10 m in highest risk areas, such as wharves and marinas, and 50 x 50 m grid-cell size in other areas (Figure 4). The 50 x 50 m grid is extended into the highest risk areas for the purpose of benthic sled sampling, because of the length of each tow (ca 50 m). The extent of the grid area was determined by water depth (20 m) for the purposes of sled sampling. Outputs from hydrodynamic modelling were used to predict dispersion of propagules from the port areas for other ports in the target-surveillance programme but the late addition of Port Taranaki precluded this approach. In the absence of this information, coastal features (headlands) likely to act as boundaries of sediment-transport cells were chosen as the alongshore boundaries. The individual locations surveyed within each habitat type and stratum are then dispersed uniformly across the grids. Sampling locations are offset by one grid cell for each subsequent survey, so that no location will be sampled more than once over the course of the surveillance programme. These predetermined locations are exported from GIS as map coordinates and loaded into GPS units to allow the field teams to locate positions in the field. Where a preassigned location cannot be sampled because of constraints such as the depth of water, presence of a vessel on a berth, or source of danger to the field team (such as areas of high vessel movement), a new location is chosen (referring to maps of past sampling locations to ensure that locations are not inadvertently resampled) and its location recorded and later mapped in GIS.

Figure 4 Example of (upper) the 10x10-m grid used to allocate sampling locations in highest-risk parts of a survey area and (lower) the 50x50-m grid used in other parts of the survey area and for benthic sledding. Each dot in the figures represents a grid cell.



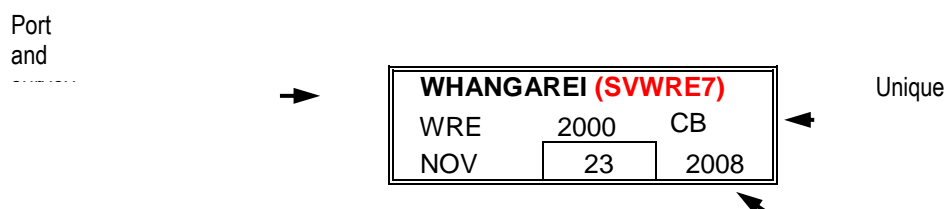
SAMPLE LABELLING AND PROCESSING

A documented labelling and audit system for biological samples collected during each survey was developed at the start of the first phase of this programme. It proved to be very effective and provided traceability of samples/specimens from collection to identification. It included the use of standardized recording sheets for each sampling method used and log sheets for material retained for subsequent identification (for both the biological material, material subsampled for DNA analysis, and any photographs taken of the material at the time of

collection). Recording and log sheets were formatted in Microsoft Excel, and data were transcribed to Excel spreadsheets at the end of each survey. Data recorded for each sample included date, time, precise location (including GPS coordinates), method of sampling, numbers of target and selected non-target species collected, individual identifying numbers for any material retained, and environmental data. This system will be retained for the proposed study and will be formally documented in the Design Report for MAFBNZ's approval. Collection and recording of environmental data will include the items listed in Table 10 of the contract. Electronic data recording devices (Hewlett Packard iPAQ hand-held computers) were used during the related port baseline surveys (ZBS2000-04) and their use will be trialled the present study and will be used if they prove reliable and reduce time needed for recording. Copies of the data sheets to be used in the present phase of the programme are included in Appendix 4.

Sample labelling

All samples are sorted on site and any specimen to be retained (all primary target species, representative samples of *Eudistoma elongatum*, and any suspicious individuals whose identity is uncertain) is allocated a label (see below) with a unique identifying number (the "sample lot code" including the identity of the port) and placed, with the label, in an individual container for return to the laboratory. The sample lot code is recorded on the sample data sheet against the sample in which it was found, linking the specimen(s) to its exact location and date of collection (which are included on the data sheet – see Appendix 4). Sample lot codes are pre-allocated for each survey so that their format is consistent among surveys and there is no possibility of duplication of codes among or within surveys. The sample lot code, date of collection, method of sampling, sample number, number of specimens retained and a description of the specimens (minimally the relevant taxon) are also recorded on a field sample lot register sheet (Appendix 4.1), providing a list of all specimens retained during the survey in question, by date and type of sample (crab trap, sled, etc.).



Sample processing

At the end of each day, all specimens retained are returned to the field laboratory and their labels and sample lot codes checked against the sample register. Where the sample container contains more than one taxon, specimens are separated into taxa and placed in separate containers (suitable for intermediate-term storage – i.e. until they are processed by MITS) with a label bearing the sample lot code and a 2-letter taxon code (which will thereafter form part of the unique identifier for that specimen). Specimens are preserved in the chemical appropriate to that taxon (the team member responsible for sample processing is provided with a list of the appropriate fixative and preservative to use with each taxon), and all samples are entered into a sample record sheet (Appendix 4.5), showing the number of individuals of each taxon present in that sample (as identified by the sample lot code).

Taxon-specific methods have been developed for fixing/preserving specimens of target and non-target species (Table 9). Note that specimens will be transferred to the appropriate long-term preserving agent by MITS.

Table 9 Methods for fixing/preserving specimens of target and non-target species collected during surveillance surveys.

Fixing/preserving agent	Taxon	Notes
5% formalin	Algae except bladed red forms	
10% formalin	Ascidians (colonial)	Relax first in menthol and photograph
	Brachiopods	
	Ctenophores	Photograph
	Ectoprocts	
	Fish	Photograph
	Hydroids	
	Jellyfish	Relax first in menthol and photograph
	Nudibranchs	
	Sea anemones	Relax first in menthol and photograph
	Worms	
80% ethanol	Ascidians (solitary)	Photograph
	Bryozoans	
	Crustaceans	
	Echinoderms	Photograph holothurians
	Hard corals	
	Molluscs (no shell)	Relax first in menthol and photograph
	Molluscs (with shell)	
	Soft corals	Relax
	Sponges	Photograph
Other	Red bladed algae	Press. Keep piece for DNA analysis
		(clean off epiphytes, wrap in tissue and place in bag with silica gel).

Sample reporting and despatch to MITS

Any suspected Unwanted Species (primary target species, excluding *Styela clava*) or suspected non-indigenous or cryptogenic species not previously recorded in New Zealand will be reported as soon as possible (and within 48 hours) by the field team leader to one of the project leaders (Graeme Inglis or Don Morrissey) who will, in turn, inform the MAFBNZ Exotic Diseases hotline (0800 80 99 66) and the MAFBNZ Biosecurity Surveillance Group Manager (again, within 48 hours of discovery). In the event that the field team leader is unable to contact either of the project leaders within 48 hours, they will contact the hotline and MAFBNZ Group Manager directly. MAFBNZ will issue a submission number to be attached to the specimen (in addition to its existing unique NIWA identifier) and will alert MITS that it is to be dealt with as a priority.

Samples reported via the MAFBNZ hotline will be despatched to MITS as soon as possible. MITS will classify these samples as *urgent* and, where possible, will log them, send them to the relevant taxonomist, and receive an identification back within 48 hours⁷. The person despatching the samples will inform MITS when they have been sent and provide the name of a field-team contact person, and will include a copy of the sample register with the specimens. An electronic version of the sample register will be sent as soon as possible.

⁷ Email correspondence between Brendan Gould (MAFFBNZ) and Shane Ahyong (MITS) 24 July 2008.

Following the discovery of *Sabella spallanzanii* in the Port of Lyttelton during the target-species surveillance in March 2008, and during the target-species surveillance of Waitemata Harbour in August 2009, any large sabellid worms will be treated as urgent samples by MITS.

All other specimens are then submitted to MITS as soon as possible, and within a week of completion of fieldwork (this allows for travel back to base from remote ports, completion of sample logging, packaging and despatch). If despatch is likely to be delayed beyond a week, MITS and the project leader(s) are to be informed of the delay and advised of the likely date of despatch. This allows for samples to be held until all sampling is completed when this is not possible within the main block of field work, so that all samples from the survey can be despatched together. The person despatching the samples will inform MITS when they have been sent and provide the name of a field-team contact person, and will include a copy of the sample register with the specimens. An electronic version of the sample register will be sent as soon as possible. MITS will treat these samples as *priority* and aim for a 1-week turnaround (from receipt of sample to receipt of identification).

All shipments will be accompanied by dangerous-goods documentation appropriate to the preserving chemicals used.

Contact and delivery details for MITS

Delivery details:

Serena Cox

NIWA Marine Invasives Taxonomic Service

NIWA

301 Evans Bay Parade

Greta Point

Wellington

NEW ZEALAND

Contact details:

s.cox@niwa.co.nz

Phone: 04-386-0300 (ext 7364)

Special Requirements:

Please provide MITS with as much advance notice of the dates of fieldwork as possible, to allow preparation.

Data entry and archiving

Data recorded on the field sheets are entered into an Excel spreadsheet (designed in the same format as the datasheets) and checked (not by the same person who entered them).

Coordinates of all sampling locations are then mapped in GIS (ArcView) and all data are imported to a Microsoft Access database for final storage. All files are stored on the project server at NIWA's Greta Point, Wellington campus and are backed up daily. GIS data are currently georeferenced to WGS84 but will be converted to NZGD2000 before being provided to MAFBNZ, along with the Access database.

Acknowledgements

Thanks to Helen Roulston for preparation of maps, John Carter and Helen Roulston for development of sample-allocation grids, Shane Ahyong, Serena Cox, Isla Fitridge and Andrew Hosie for development of the sample-processing protocols, and Isla Fitridge and Liv Johnston for preparation of data sheets. Isla Fitridge, Oli Floerl and Nick Gust are

acknowledged for their contributions to the species summaries (Appendix 2). Thanks to Oli Floerl for reviewing an earlier version of this report.

References

- Binns, M.R., Nyrop, J.P., Van Der Werf, W. 2000. Sampling and monitoring in crop protection. CABI Publishing, New York. 281 pp.
- Black, K.P., McComb, P.J. 2000. Port Taranaki maintenance dredging consent renewal studies. Report 3: Site selection, effects and outcomes. Department of Earth Sciences, University of Waikato report prepared for Westgate Transport Ltd, January 2000.
- Cameron, A. 2002. Survey Toolbox for Aquatic Animal Diseases: A Practical Manual and Software Package. Australian Centre for International Agricultural Research., Canberra. 376 pp.
- Cannon, R.M. 2002. Demonstrating disease freedom – combining confidence levels. Preventative Veterinary Medicine 52: 227-249.
- Carlton, J.T., Thompson, J.K., Schemel, L.E., Nichols, F.H. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. 1. Introduction and dispersal. Marine Ecology Progress Series 66: 81-94.
- Carter, L., Pickrill, R.A., Irwin, J. 1981. Seabed investigations, Port Taranaki. NZOI Oceanographic Field Report No. 19, Wellington, January 1981, 10p.
- Carter, P.C.S. 1989. Risk assessment and pest detection surveys for exotic pests and diseases which threaten commercial forestry in New Zealand. New Zealand Journal of Forestry Science 19: 353-374.
- Chapman, J.W., Carlton, J.T. 1991. A test of criteria for introduced species: the global invasion by the isopod *Synidotea laevidorsalis* (Miers, 1881). Journal of Crustacean Biology 11: 386-400.
- Cole, R., McComb, P. 2000. Port Taranaki maintenance dredging consent renewal studies: Report 4 - biological description and assessment. Prepared for Westgate Transport Ltd. Wellington, NIWA Client Report No. WTL00403/1.
- Cranfield, H., Gordon, D., Willan, R., Marshall, B., Battershill, C., Francis, M., Nelson, W., Glasby, C., Read, G. 1998. Adventive marine species in New Zealand. NIWA Technical Report No. 34. Hamilton, NIWA.
- Currie, D.R., McArthur, M.A., Cohen, B.F. 2000. Reproduction and distribution of the invasive European fanworm *Sabella spallanzanii* (Polychaeta: Sabellidae) in Port Phillip Bay, Victoria, Australia. Marine Biology 136: 645-656.
- Don, G.L. 1981. The ecological impact of dredging and spoil disposal at Port Taranaki. Proposed development at Port Taranaki: environmental impact assessment. Bruce Wallace and Partners.
- Garnham, J. 1998. Distribution and impact of *Asterias amurensis* in Victoria. Pages 18-21 in Goggin, L. C. (ed.s). Proceedings of a meeting on the biology and management of the introduced seastar *Asterias amurensis* in Australian waters. Technical Report No. 15. Centre for Research on Introduced Marine Pests, CSIRO Division of Marine Research., Hobart, Australia.
- Gaston, K. J. 1994. Rarity. Chapman and Hall, London, UK, 205 pp.
- Gibb, J.G. 1983. Report on coastal processes, port development and beach restoration at New Plymouth, Taranaki Region. Water and Soil Planning Section Internal Report. National Water and Soil Conservation Organisation.
- Gray, J.S. 2002. Species richness of marine soft sediments. Marine Ecology Progress Series 244: 285-297.
- Green, R.H., Young, R.C. 1993. Sampling to detect rare species. Ecological Applications 3: 351-356.

- Hayes, K. R., Cannon, R., Neil, K., Inglis, G. 2005. Sensitivity and cost considerations for the detection and eradication of marine pests in large commercial ports. *Marine Pollution Bulletin* 50: 823-834.
- Hayes, K., Sliwa, C., Migus, S., McEnnulty, F., Dunstan, P. 2004. National priority pests. Part II, Ranking of Australian marine pests. Report undertaken for the Department of Environment and Heritage by CSIRO Marine Research. Commonwealth of Australia.
- Henwood, J.W. 1989. Deepening of Port Taranaki by backhoe dredge. *Transactions of the Institution of Professional Engineers New Zealand* 16(1/CE): 1-8.
- Hewitt, C., Martin, R. 2001. Revised protocols for baseline surveys for introduced marine species – survey design, sampling protocols and specimen handling. CRIMP Technical Report No. 22, Centre for Research on Introduced Marine Pests, Hobart.
- Inglis, G.J. 2001. Criteria for identifying and selecting high value locations and locations at risk of invasion by exotic marine organisms in New Zealand. Final research report for Ministry of Fisheries research project ZBS2000/01A, objectives 1 and 2. Wellington. 27p, National Institute of Water and Atmospheric Research.
- Inglis, G., Gust, N., Fitridge, I., Floerl, O., Woods, C., Hayden, B., Fenwick, G. 2006a. Port Taranaki. Baseline survey for non-indigenous marine species (Research Project ZBS2000/04). MAFBNZ Technical Paper No. 2005/04, Wellington, prepared for MAFBNZ Post Border Directorate by NIWA, March 2006.
- Inglis, G., Hurren, H., Gust, N., Oldman, J., Fitridge, I., Floerl, O., Hayden, B. 2006b. Surveillance design for early detection of unwanted exotic marine organisms in New Zealand. Biosecurity New Zealand Technical Paper No. 2005-17, Wellington, prepared by NIWA, April 2006.
- Inglis, G., Gust, N., Fitridge, I., Floerl, O., Woods, C., Kospartov, M., Hayden, B., Fenwick, G. 2008. Port Taranaki. Second baseline survey for non-indigenous marine species (Research Project ZBS2000/04). MAFBNZ Technical Paper No. 2008/07, Wellington, prepared for MAFBNZ Post Border Directorate by NIWA, May 2008.
- Martin, R., Proctor, C. 2000. Tasmanian Marine Farm Monitoring Project, Centre for Research on Introduced Marine Pests, CSIRO, Hobart, Tasmania.
- May, J.T., Brown, L.R. 2001. Chinese mitten crab surveys of San Joaquin River Basin and Suisun Marsh, California, 2000. Open-File Report 01-396 Prepared for the U.S. Geological Survey in Cooperation with the Interagency Ecological Program., Sacramento, California. 25 pp.
- McComb, P. 2001. Statement of evidence in the Matter of an Application by Westgate Transport Ltd for coastal permits to carry out maintenance dredging of Port Taranaki, New Plymouth.
- Morrisey, D., Peacock, L., Inglis, G., Floerl, O. 2007. Surveillance for early detection of unwanted exotic marine organisms in New Zealand: summer 2005-2006. MAFBNZ Research Project ZBS2001/01. MAFBNZ Technical Paper No. 2007/02, prepared by NIWA, Nelson, December 2007, 171p.
- New Zealand Food Safety Authority (2003). Non-Commercial Marine Biotoxin Monitoring in New Zealand Risk-Based Programme Enhancement - Final Report May 2003.
- Parry, G.D., Cohen, B.F. 2001. The distribution, abundance and population dynamics of the exotic seastar *Asterias amurensis* during the first three years of its invasion of Port Phillip Bay (incorporating a report on the Bay Pest Day, 2 April 2000). Marine and Freshwater Resources Institute Report no. 33. Marine and Freshwater Resources Institute, Queenscliff.
- Port Taranaki Ltd 2008. Annual report 2008. New Plymouth, Port Taranaki Ltd.
- Rogers, D.M. 1995 Water Quality, Surficial Sediment Quality and Hydrodynamics within the Lee Breakwater Basin, Port Taranaki. MSc Thesis, University of Waikato, 169p.
- Sinner, J., Forrest, B., Taylor, M. 2000. A strategy for managing the Asian kelp *Undaria*: final report. Cawthron Report No. 578, prepared for Ministry of Fisheries, 119p.

- Statistics New Zealand (2004). Overseas Cargo Statistics.
<http://www2.stats.govt.nz/domino/external/pasfull/pasfull.nsf/7cf46ae26dcb6800cc26a62000a2248/4c2567ef00247c6acc256f16000eb4a4?OpenDocument>, accessed 12/05/05.
- Statistics New Zealand 2006a. Exports and Imports Tables.
<http://www.stats.govt.nz/products-and-services/table-builder/table-builder-exportsimports.htm> accessed 8/12/06.
- Statistics New Zealand 2006b. Overseas cargo statistics - information releases.
<http://www.stats.govt.nz/products-and-services/info-releases/oseas-cargo-info-releases.htm> accessed 8/12/06.
- Taranaki Regional Council 2009. Navigation and safety and marine oil spill annual report 2008/2009. Taranaki Regional Council Document No. 624107, 13p.
<http://www.trc.govt.nz/publications/sa+annual+reports/navigation09.pdf>. htm accessed 13/8/09.
- Taylor, M., MacKenzie, L. 2001. Delimitation survey of the toxic dinoflagellate *Gymnodinium catenatum* in New Zealand. Cawthron Report 661, prepared for Ministry of Fisheries, 12pp..
- Thresher, R.E., Proctor, C., Ruiz, G.M., Gurney, R., MacKinnon, C., Walton, W., Rodriguez, L., Bax, N. 2003. Invasion dynamics of the European shore crab, *Carcinus maenas*, in Australia. Marine Biology 142: 867-876.
- Veldhuizen, T.C. 2000. Gear type selection for the Chinese Mitten Crab habitat use study. IEP Newsletter 13(1): 10.
- Veldhuizen, T.C., Stanish, S. 1999. Overview of the life history, distribution, abundance and impacts of the Chinese mitten crab, *Eriocheir sinensis* California Department of Water Resources, Environmental Services Office, Sacramento, California, USA (<http://www.anstaskforce.gov>).
- Venette, R.C., Moon, R.D., Hutchison, W.D. 2002. Strategies and statistics of sampling for rare individuals. Annual Reviews in Entomology 47: 143-174.
- Westgate Transport Ltd 2004. Annual Report 2004. New Plymouth, Westgate Transport Ltd.
- Westgate Transport Ltd 2005. Annual Report 2005. New Plymouth, Westgate Transport Ltd.
- Wolff, W., Reise, K. 2002. Oysters as a vector for the introduction of alien species into Northern and Western European coastal waters. In: Leppakoski, E., Gollasch, S., Olenin, S. (eds) Invasive Aquatic Species in Europe. Distribution, Impacts and Management, pp. 193-205. Kluwer Academic Publishers, Dordrecht.
- Yamada, S.B., Kalin, A., Hunt, C. 2001. Growth and longevity of the European green crab, *Carcinus maenas*, in the Pacific northwest. (Unpublished manuscript).
- Yamada, S.B., Kalin, A., Hunt, C.E., Dumbauld, B.R., Figlar-Barnes, R., Randall, A. 2004. Growth and persistence of a recent invader *Carcinus maenas* in estuaries of the northeastern Pacific. Biological Invasions 7: 309-321.

Appendices

APPENDIX 1: LETTER SENT TO STAKEHOLDERS.

Fields highlighted in yellow are replaced with appropriate text for each survey at each location.

Targeted surveillance for non-indigenous marine species in New Zealand,

PORT NAME MONTH YEAR

We propose to carry out this survey during the period INSERT DATES. The work will cover the whole of the harbour, including INSERT NAMES OF PORT/WHARF AREAS TO BE SAMPLED.

Background to the survey

The survey is being done by NIWA with funding from Ministry of Agriculture and Forestry Biosecurity New Zealand (MAFBNZ), and repeats the surveillance work done in 2002-2004 at ports around the country. This project provides surveillance for a group of potentially invasive marine animals and plants that MAFBNZ believes present a significant threat to New Zealand. One of them – the sea squirt *Styela clava* – is already present in New Zealand, and in this case the project will monitor its spread). These surveys will be repeated at six-monthly intervals.

Sampling methods

We will be sampling by setting traps for crabs and starfish, dredging for animals on the seabed using a small (1-m wide mouth) scallop dredge, and diving to inspect wharf piles, walls and rocky shores. **All access to port areas will be from the water**, using vessels of 4-6 m length, equipped with VHF radio. We will inform PORT NAME Harbour Radio whenever we enter and leave port areas. INSERT NAME OF ANY MARINAS TO BE SAMPLED will be accessed by boat or from the shore (pontoons). NIWA staff will not board any boat berthed in the marina at any time. ADD INFORMATION RELEVANT TO ANY OTHER STAKEHOLDERS THIS WILL BE SENT TO

- Crab and starfish traps will be deployed on lines with anchors and a marker buoy for periods of 24 hours. Buoys bear NIWA's name and contact telephone number.
- All traps will be deployed away from shipping lanes and will only be deployed on berths when the notice of shipping movements on the INSERT NAME OF PORT AUTHORITY website indicates that the berth will be empty during the period of deployment. We will contact PORT NAME Harbour Radio just prior to deployment to confirm that there have been no changes to advertised shipping movements. Traps in marinas will be placed so that they do not interfere with the movements of vessels. If there is any doubt about deployment we will contact the Marina Manager.
- Dredging and diving around port areas will also avoid shipping lanes, and diving on wharf piles and walls will be timed to avoid shipping movements or the presence of ships on berths. A support boat showing a dive flag will accompany the divers. Again, we will confirm with PORT NAME Harbour Radio prior to

starting to sample. In the marina a surface observer with a dive flag (either in a boat or on the pontoons) will monitor the diver and warn vessels that there is a diver in the water.

We are very grateful to PORT NAME, the marinas and their staff for their cooperation with this project. If you have any questions regarding any aspects of the work, please do not hesitate to contact:

The field-team leader, ADD YOUR NAME, DDI AND EMAIL,

NIWA programme leaders

Don Morrisey, telephone 03-545-7744, email d.morrisey@niwa.co.nz

Graeme Inglis telephone 03-348-8987, email g.inglis@niwa.co.nz

or

MAFBNZ contact

Brendan Gould telephone 04 819 0548, email Brendan.Gould@maf.govt.nz

APPENDIX 2: SUMMARIES OF THE HABITAT ASSOCIATIONS AND LIFE HISTORIES OF THE TARGET SPECIES.

Northern Pacific seastar (*Asterias amurensis*)

General information

The northern Pacific seastar, *Asterias amurensis*, naturally inhabits the northern coast of China, the coasts of Korea and Japan, and along the Russian coast to the Bering Strait. It is also found occasionally in Alaska and northern Canada (Morrice, 1995). Its distribution has since increased to several other countries, including Australia.

(<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>).

Fully-grown seastars reach sizes of 40-50 cm in diameter, with reproduction possible at 10cm, when the seastar is around one year old (CRIMP, 2000). The seastar can increase its diameter by 8cm each year. (<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>). Increasing size is also a response to food. When food is short the seastars shrink: their sexual organs also shrink which reduces fertilisation success

(<http://www.marine.csiro.au/PressReleasesfolder/99releases/seastar4jun99/backgrnd.html#gaps>).

Timing of reproduction and recruitment

In the southern hemisphere, spawning occurs during winter (July-October) when temperatures are around 10 to 12 °C. Fertilisation takes place externally

(<http://www.parliament.vic.gov.au/enrc/ballast/Ballast-30.htm>). Small eggs of approximately 150µm in diameter hatch, and develop into free-swimming larvae through a series of stages - coeloblast, gastrula, bipinnaria and brachiolaria (Bruce, 1998). A single adult female seastar can produce 10-20 million eggs each year for about 5 years. Both the eggs and larvae are planktonic, drifting in the ocean for up to two months before they settle and metamorphose into juvenile seastars.

(<http://www.parliament.vic.gov.au/enrc/ballast/Ballast-30.htm>). Based on this 60-day larval period, settlement in Australian waters has been shown to occur during mid-September (Parry *et al.* 2001).

The northern Pacific seastar lives for up to five years. It is known to reach outbreak proportions that occur in three to ten year cycles, and which last two to three years

(<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>).

Habitat and biology

Morrice (1995) suggests that in Tasmanian studies, it is unclear whether the northern Pacific seastar is present in areas due to specific habitat requirements or whether their location is dependant on their rate of spread.

Substratum type

The preferred substrata for *A. amurensis* are mud, sand or pebbles

(<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>), extending to a mixture of rock, algae and seagrass (Morrice, 1995). It is rarely found on reefs or places subject to high wave action.

However, a benthic habitat is not essential - in Tasmania, both adults and juveniles have been recorded attached to scallop longlines, mussel and oyster lines, salmon cages and spat bags (<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>). Research has shown that substratum seems important for the induction of settlement and metamorphosis - brachiolaria have shown high rates of settlement on non-geniculate coralline algae, followed by rock and mud. Sand and mussel shell did not induce settlement well. Bacterial cover on mussel lines, accompanied by the fine algae that grows on the ropes, may also provide a very attractive settlement surface (Morris and Johnson, 1998).

Food preferences

The seastar is a predator of many organisms but has a particular preference for shellfish (<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>). Other prey include sponges, crustaceans, polychaetes and fish (<http://www.parliament.vic.gov.au/enrc/ballast/Ballast-30.htm>), as well as tunicates, bryozoans and echinoderms (Morrice, 1995).

Physiological tolerances (range and preferences)

Temperature

The seastars prefer water temperatures of between 7 and 10 °C in their natural range (<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>), but can tolerate a range of 5 – 20°C. In Japan, water temperatures above 20°C limit the seastars' range, with adults losing weight and larvae dying above this temperature (Morrice, 1995, Bruce, 1998). The survival of larvae is temperature dependant, with the optimal range being between 8 to 16 °C (Bruce, 1998). However, adult seastars have been shown to adapt to warmer temperatures of up to 22 °C in countries outside their natural range, such as Australia (<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>).

Depth

The seastar is mainly found in sublittoral to subtidal areas, but can also be present at depths of up to 200m

(<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>). In Australia, it occurs in the intertidal zone down to a depth of 25m (CRIMP, 2000). Parry and Cohen (2001) have observed that in some parts of Port Philip Bay, the density of the seastar decreases at depths of <15 metres. Morrice (1995) states that in the northern Pacific, the seastar inhabits deeper water in the summer and moves into shallower water in the winter. This may be to survive summer temperatures and to move between areas.

Salinity

Little research appears to have been conducted on salinity tolerances of the northern Pacific seastar, but adults seem to be restricted to salinities above 28 psu (Morrice, 1995). In general, the seastar is sensitive to any changes in salinity and as a result is unlikely to tolerate fluctuating salinities (<http://www.fish.wa.gov.au/hab/broc/marineinvader/marine01.html>).

Optimal salinity for larval survival is 32 psu. The larvae become adversely affected by 10 minute exposures to salinities <17.5 psu and do not survive exposures to salinities <8.55 psu, when extensive cellular damage has been found to occur (Bruce, 1998).

Route of introduction

The most likely route is as seastar larvae contained in the ballast water of international vessels, although research suggests that ‘sea chests’ are another potential method of transport (Dodgshun and Coutts, 2002). Juvenile seastars found on mussel lines in Port Philip Bay, Australia, indicate a further risk of spread (Garnham, 1998).

Methods of sampling

- Parry and Cohen (2001) used a 2.7 m wide peninsula scallop dredge, covered by 25mm mesh to sample *Asterias*. Estimates of field densities were based on the number of seastars collected in a 60 second tow at a speed of 5.7 ± 0.3 knots. The average tow length was around 170 m (Parry and Cohen, 2001).
- Whayman/Holdsworth seastar traps have been designed to catch *Asterias*. Traps with a mesh size of 26mm catch more seastars than larger mesh (65mm) traps. Most seastars are caught within the first 24-48 hours. Pilchards are the more attractive bait but only for short soak times (24-48 hours). The traps effectively fish an area of approximately 30m² (Martin, 1998).
- Vertical distribution of larval asteroids can be measured using vertical tows of a 100µm free-fall plankton net with a 500mm diameter mouth and 5m in length. A choking bridle closes the net when hauled. Vertical tows are undertaken to depths of 5m, the depth at which the net completely submerges, or 15m. A small float can be tied to the end of the plankton net by 10m of fine line – when this submerges, the net has reached the appropriate depth of 15m (Parry *et al*, 2001).

Literature cited

- Bruce, B. 1998. A summary of CSIRO studies on the larval ecology of *Asterias amurensis*. In: Goggin, C. Louise (Ed.). Proceedings of a meeting on the biology and management of the introduced seastar *Asterias amurensis* in Australian waters. Centre for Research on Introduced Marine Pests (CRIMP) Technical Report no. 15.
- Centre for Research on Introduced Marine Pests (CRIMP). 2000. Marine Pest Information Sheet 4 – Northern Pacific Seastar (*Asterias amurensis*). CRIMP and CSIRO Marine Research.
- Dodgshun, T, Coutts, A. 2002. Ships’ sea chests: a “side door” for marine pests? Cawthron Institute.
- Garnham, J. 1998. Distribution and impact of *Asterias amurensis* in Victoria. In: Goggin, C. Louise (Ed.). Proceedings of a meeting on the biology and management of the introduced seastar *Asterias amurensis* in Australian waters. Centre for Research on Introduced Marine Pests (CRIMP) Technical Report no. 15.
- Martin, R. 1998. Control of seastars by physical removal. In: Goggin, C. Louise (Ed.). Proceedings of a meeting on the biology and management of the introduced seastar *Asterias amurensis* in

Australian waters. Centre for Research on Introduced Marine Pests (CRIMP) Technical Report no. 15

Morrice, MG. 1995. The distribution and ecology of the introduced northern Pacific seastar, *Asterias amurensis* (Lutken), in Tasmania. Final Report to the Australian Nature Conservation Agency Feral Pests Program Number 35. Tasmanian Museum and Art Gallery.

Morris, A, Johnson, C. 1998. Fertilisation and recruitment dynamics of *Asterias amurensis*. In: Goggin, C. Louise (Ed.). Proceedings of a meeting on the biology and management of the introduced seastar *Asterias amurensis* in Australian waters. Centre for Research on Introduced Marine Pests (CRIMP) Technical Report no. 15.

Parry, GD, Black, KP, Hatton, DN, Cohen, BF. 2001. Factors affecting the distribution of the exotic seastar *Asterias amurensis* during the early phase of its invasion of Port Phillip Bay. 1. Hydrodynamic factors. Marine and Freshwater Resources Institute Report No. 38. Marine and Freshwater Resources Institute, Queenscliff.

Parry, GD, Cohen, BF. 2001. The distribution, abundance and population dynamics of the exotic seastar *Asterias amurensis* during the first three years of its invasion of Port Phillip Bay (incorporating a report on the Bay Pest Day, 2 April 2000). Marine and Freshwater Resources Institute Report no. 33. Marine and Freshwater Resources Institute, Queenscliff.

Asian clam (*Potamocorbula amurensis*)

General information

The Asian clam, *Potamocorbula amurensis*, is a native of estuaries from southern China (22° N latitude) to southern Siberia (53° N) and Japan (Cohen and Carlton, 1995). However, it has extended its range to establish abundant populations in California, USA, particularly San Francisco Bay. Asian clams are euryhaline at all stages of development, and reach settlement 17-19 days after fertilisation (Nicolini and Penry, 2000).

Timing of reproduction and recruitment

Field studies in San Francisco Bay suggest that the clam spawns throughout the year, although site-specific seasonal reproduction appears to be related to food supply (Parchaso and Thompson 2002). The eggs are negatively buoyant, so fertilisation and initial development occur in more saline bottom waters. It takes 48 hours for development to the straight hinged larval stage through several life phases – fertilised egg, two-cell stage, four-cell stage, blastula, trochophore). At 17 – 19 days after fertilisation, the bivalve settles at a shell length of approximately 135 µm. Newly settled clams can reproduce within a few months (Nicolini and Penry, 2000). Juvenile clams studied in San Francisco Bay had a mean shell length of 1.7 mm. By the time they were under a year old, shell length was approximately 11 mm (Cohen and Carlton, 1995). Adults generally reach a length of 20 – 30 mm (NZ Ministry of Fisheries, 2001).

Studies in San Francisco Bay have shown that the clam displays a complex picture of patchy recruitment in space and time, which is expected for an invasive eurytopic species (Carlton *et al.* 1990). The zone of greatest recruitment shifts dramatically with changes in flow - high riverine outflow conditions may reduce clam densities, but the clams are quick to repopulate brackish water habitats when high flows abate (Peterson, 1998).

Habitat and biology

Substratum type

The Asian clam is pervasive with regard to habitat. It can invade environments which are nearly freshwater, creeks and sloughs, intertidal sand-mud flats, and on a wide range of subtidal soft bottomed substrata - flocculant mud, coarse sand, peat and hard clay (Carlton *et al.*, 1990). It typically sits with one-third to one-half of its length exposed above the sediment surface. (Cohen and Carlton, 1995). It has been found in very high densities in the benthic layer in the majority of San Francisco Bay estuary, at up to 48,000 individuals.m⁻² (Peterson, 1998). Research in laboratory aquaria has shown that its behaviour can lead to the formation of depressions in the underlying substrate, which can significantly disturb sediment layers to a depth of about 1cm. The highly altered, complex surface left behind may cause difficulties for other mobile and sedentary infauna, thus allowing the clam to dominate (Carlton *et al.*, 1990).

Feeding

Potamocorbula amurensis is an efficient suspension feeder (Thompson *et al*, 1991). Examination of faeces from specimens collected in San Francisco Bay show that the clam ingests both planktonic and benthic diatoms. It also filters bacterioplankton as well as phytoplankton, though at lower efficiency, and assimilates both with high efficiency. Laboratory experiments have shown that the bivalve can also readily consume certain copepod nauplii (Kimmerer *et al* 1994). Other research suggests it may feed on the larvae of other benthic organisms (Cohen and Carlton, 1995).

Physiological tolerances (range and preferences)

The Asian clam is one of the few species of bivalves able to tolerate virtually any salinity, withstand tropical or cold temperate waters and survive in polluted environments. Research in San Francisco Bay suggests that the Asian clam has spread rapidly, irrespective of sediment type, water depth and salinity (Thompson *et al*. 1991). The following information highlights the wide range of physiological tolerances that this species displays.

Temperature

Their latitudinal range in Asia suggests that Asian clams can survive a temperature range of 0 – 28°C (Cohen and Carlton, 1995). There is very little information for *P. amurensis*, but data for the similar Chinese corbulid *P. laevis* (found at approximately the same latitude as San Francisco Bay) suggest that gametogenesis requires water temperatures ranging from 12 – 23°C. Reproductively active *P. amurensis* have been seen in San Francisco Bay in water temperatures ranging from 6 – 23°C (Parchaso and Thompson 2002). Fertilised eggs of *P. laevis* are shed at temperatures of between 16 and 20°C. Growth rates are greatest when water temperatures are between 22 and 28°C. Growth rates decline below 17°C, and growth ceases below 11.8°C (Carlton *et al*, 1990).

Depth

The clams live both subtidally and intertidally (Cohen and Carlton, 1995), but primarily subtidally (Carlton *et al*, 1990).

Salinity

The Asian clam can survive in a range of salinities from almost freshwater (< 1 psu) to full-strength seawater (32 – 33psu) (Cohen and Carlton, 1995, Carlton *et al*, 1990, <http://www.fish.wa.gov.au/hab/broc/marineinvader/marine08.html>) but long-term survival of adults is highest at salinities from 5 to 25 psu (Nicolini and Penry, 2000). Spawning and fertilisation can occur at salinities from 5 – 25 psu, with a maximum at about 10 – 15 psu. Eggs and sperm can tolerate at least a 10-psu step increase or decrease in salinity. Studies have shown that fertilisation and initial development tend to occur in the more saline bottom waters of San Francisco Bay. Embryos of two hours old have been shown to tolerate salinities from 10 – 30 psu, and at 24 hours old they can tolerate the same wide range of salinities that adult clams can. However, any *rapid* changes in salinity may adversely affect larval growth (Nicolini and Penry, 2000).

Route of introduction

The initial introduction of the Asian clam to San Francisco Bay seems to have been as veliger larvae transported in ballast water by trans-Pacific cargo ships. The clams' ability to tolerate wide changes in salinity suggests it can survive incomplete oceanic exchanges of ballast water (Nicolini and Penry, 2000). The infaunal habitat of the clam suggests that it did not arrive as a fouling organism (Carlton *et al.*, 1990).

Methods of sampling

- Carlton *et al.* (1990) described a combination of sampling devices that were used to sample *Potamocorbula*, including a modified Van Veen grab, a Ponar grab and a Van Veen grab, that sampled between 0.05 and 0.1 m² of sediment. Samples were sieved through screens of 0.5 mm to 1mm mesh size. Between 3 to 5 replicate grabs were taken at each sampling station.
- Peterson (1998) describes an extensive survey for *Potamocorbula* in San Francisco Bay using a Ponar grab.

Literature cited

- Carlton, J.T., Thompson, J.K., Schemel, L.E., Nichols, F.H. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. 1. Introduction and dispersal. *Marine Ecology Progress Series* 66: 81-94.
- Cohen, A.N, Carlton, J.T. 1995. Nonindigenous aquatic species in a United States estuary: a case study of the biological invasions of the San Francisco Bay and delta. A report for the United States Fish and Wildlife Service, Washington DC and the National Sea Grant College Program, Connecticut Sea Grant (NOAA Grant number NA36RG0467).
- Kimmerer, W., J.E. Gartside, and J.J. Orsi. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton in San Francisco Bay. *Marine Ecology Progress Series* 113:81-93.
- NZ Ministry of Fisheries, 2001. Beware invaders of the deep: A guide to identifying marine pests in New Zealand's Waters. Information booklet produced by the Ministry of Fisheries, in collaboration with the Cawthron Institute and NIWA.
- Nicolini, M.H., Penry, D.L. 2000. Spawning, fertilisation, and larval development of *Potamocorbula amurensis* (Mollusc: Bivalvia) from San Francisco Bay, California. *Pacific Science* 54: pp 377-388.
- Parchaso, F., Thompson, J.K. 2002. Influence of hydrologic processes on reproduction of the introduced bivalve *Potamocorbula amurensis* in Northern San Francisco Bay, California. *Pacific Science* 56(3): 329-345.

Peterson, H. 1998. Results of the 1995 *Potamocorbula* Spatial Distribution Survey. California Department of Water Resources. In Abstracts from the Eighth International Zebra Mussel and Other Nuisance Species Conference, Sacramento California, March 16-19, 1998.

Thompson, J.K., Schemel, L.E, Nichols, S.J. 1991. An Asian bivalve, *Potamocorbula amurensis*, invades San Francisco Bay with remarkable speed and success. *Journal of Shellfish Research*, 10: 259.

Chinese mitten crab (*Eriocheir sinensis*)

General Information:

The Chinese mitten crab *Eriocheir sinensis* is a burrowing crab native to mainland China and coastal rivers and estuaries of the Yellow Sea. It is a palm-sized greyish-brown grapsid crab with small white pincers protruding from hairy brown claws. The native range of the mitten crab extends from the southern border of North Korea (40°N latitude) to Hong Kong (22°N). It has established introduced populations in Vietnam, northern Europe and the west coast of America. The first specimens to be found in Europe were reported from near Hamburg in Germany 1912 (Panning 1939). Since then, mitten crabs have spread from Finland to the Atlantic coast of southern France and to the UK, Russia, Holland, Belgium, the Czech republic, Denmark, Sweden, France, Poland and Portugal and Spain. The first reported occurrence of the mitten crab in North America was in the Detroit River in 1965 by the city of Windsor, Canada. Later, in 1973, commercial fishermen netted several crabs in Lake Erie near Erieau and Port Stanley, Ontario, Canada (Nepszy and Leach, 1973). In June 2006 a specimen was caught in Chesapeake Bay (SERC 2004). On the west coast, it was first reported from San Francisco Bay in 1992 where it has since become well-established (Halat and Resh 1996). Ballast water introductions have been blamed, but speculation also exists about possible deliberate release into the U.S.A.

Eriocheir sinensis is a catadromous species that lives most of its life in freshwater environments. Mature males and females migrate during late summer to tidal estuaries where they mate and spawn. Adults (Maximum body size 10-cm carapace width, but more commonly between 5 and 8 cm) are capable of very long distance migrations e.g. over 1000km in the Yangtze River (Cohen and Carlton 1995). After mating the females are thought to continue seaward, over-wintering in the deeper water and returning to brackish water in the spring to hatch their eggs (Panning 1939). The movement of crabs to deeper water and the timing of egg hatching/larval release is temperature dependent. Winter temperatures are much colder in Europe than San Francisco, which is probably why crabs there move to deeper water and why hatching is delayed until spring. In the San Francisco Estuary, preliminary data indicate that the adult crabs remain in the spawning areas (~ 20psu) and hatching occurs in November/December and again in March. The timing of hatching varies yearly depending upon winter water temperatures. Settled juvenile crabs gradually move upstream into brackish (1-5 psu) and fresh water to complete the life cycle.

Mitten crab 'plagues' of extreme numbers have been reported from Germany in the mid 1930's (Panning 1939) and in the Netherlands in 1981 (Ingle, 1986). Adults are capable of emerging from water and crossing dry land when migrating.

Timing of reproduction and recruitment

Crabs mature at different ages according to locality. Maturity has been reported at ages of 3 to 5 years in Europe (Panning 1939), 1 to 2 years in China (Cohen and Carlton 1995) and 2 to 3 years in California (Veldhuizen and Stanish 1999). Each female produces from 250,000 to 1 million eggs, which hatch in late spring or early summer. In laboratory culture, the larval period lasts for 1–2 months and the larvae develop through five zoeae and a megalopa stage (Kim and Hwang 1995). After the final larval moult the juvenile crab settles to the bottom in late spring and begins its migration upstream (Panning, 1939; Ingle, 1986; Anger, 1991). Experiments indicate that complete development of larvae is not possible in rivers or in brackish estuarine conditions (Anger 1991).

Habitat and Biology:

Substratum type

The normal habitat of the juveniles is the bottoms and banks of brackish and freshwater rivers and estuaries, individuals prefer hard bottoms and areas covered with submerged plants (Nepzy and Leach 1973). Older juveniles are found in a diversity of habitats including silt, gravel, and open unvegetated stream channels. In freshwater habitats of San Francisco Bay, *E. sinensis* is most common in areas with steep, vegetated banks that are high in clay content. Burrows are concentrated underneath the root profile of the aquatic macrophytes lining the banks, which mainly consists of *Scirpus* (Halat and Resh 1996). Submerged aquatic vegetation is an important component to the habitat. It provides cover and high concentrations of invertebrates (Veldhuizen 2000).

In Asia and Europe mitten crabs live in burrows dug in river banks or in rice paddies in coastal areas (Cohen and Carlton 1995). Young mitten crabs are found in tidal freshwater areas and usually burrow in banks and levees between high and low-tide marks. Optimal rearing habitat for juveniles is areas with still or slow velocity water, a stable water depth, low turbidity, and warm temperatures (ranging from 20°C to 30°C, with optimal growth at 24°C to 28°C) (Veldhuizen 2000). Mitten crabs apparently do not burrow as extensively in non-tidal areas. Older juveniles are found further upstream than young ones and both adults and juveniles can move hundreds of km.

In China, recently settled juvenile mitten crabs are harvested during spring tides in late May and June when they congregate over sandy bottom areas in water of 1 to 3 ‰ (Hymanson *et al.* 1999)

Food preferences

The mitten crab is known to be predominantly an omnivorous, opportunistic feeder, although feeding habits change as they mature. Juvenile crabs mainly eat vegetation (Halat and Resh 1996) primarily filamentous algae (Veldhuizen and Stanish 1999). As they mature they also prey on small invertebrates, especially worms and clams so that adults and juveniles are considered omnivorous (<http://www.wsg.washington.edu>). Gut content analysis of crabs in the San Francisco Bay area revealed a high proportion of vegetative matter, with low amounts of invertebrates, regardless of the size of the crab or the habitat from which it was captured (Rudnick *et al.* 2000).

Vegetation type

Juveniles were observed taking cover in floating vegetation, especially water hyacinth in the USA (Hieb and Veldhuizen 1998). An ongoing study by Veldhuizen is currently assessing habitat

associations for this crab in the San Joaquin Delta, but results are presently unavailable. In Asia, the juveniles can be associated with rice paddies (Panning 1939). An attempt to characterise habitat associations of mitten crabs in the San Joaquin River in 2000 failed to capture any individuals (May and Brown 2000).

Physiological Tolerances (range and preferences):

Temperature

Adult mitten crabs exhibit a wide range of temperature tolerances. Growth ceases only at temperatures below 7°C and above 30°C (Rudnick *et al.* 2000). All larval stages of the Chinese mitten crab show a clear preference for warm water, however (15° to 18°C), and temperatures below 12°C do not allow any development beyond the first zoeal stage in the laboratory (Anger 1991). Adults can tolerate temperatures as low as 0 °C for a week and temperatures up to 31 °C are suitable for juveniles (Veldhuizen and Stanish 1999).

Depth

Juvenile mitten crabs appear to occur mostly in shallower waters (i.e. < 10m) (Veldhuizen and Stanish 1999, preliminary results), with largest densities found in areas with an average depth of 2 m, which corresponds to the depth of submerged aquatic vegetation (Veldhuizen 1999). However, through the winter sexually mature females are thought to move to “deep” water to develop their fertilised eggs. Adult mitten crabs are highly tolerant of desiccation and are able to remain on land for several hours without mortality. Veldhuizen (pers. comm.) compared the relative abundance of juvenile mitten crabs among six different habitat types - shallow (0-2.4 m) vegetated natural substrate, shallow unvegetated natural substrate, shallow vegetated rock substrate, shallow non-vegetated rock, mid-depth channels (2.5 – 4.9 m), and deep channels (5 - 10 m) - that occurred in a tidal freshwater marsh. Crabs occurred in all habitat types, but were overall more abundant in shallow (0 to 2.4 m) vegetated areas with natural substrate. Most of the crabs ranged in size from 20 to 38 mm, average size was 28 mm.

Salinity

Juvenile and adult Chinese mitten crabs are extremely euryhaline (i.e. high range of tolerated salinities) and its osmoregulatory abilities appear well developed (Onken 1996). By hyper-regulating the ionic content of their body fluids, the crabs can quickly adapt from high to low salinity environments (Welcomme and Devos 1991 cited in Rudnick *et al.* 2000). Different larval stages are known to vary in their salinity tolerances. The first zoeal stage, which occurs in seawater, is strongly euryhaline, but successive zoeal stages become increasingly stenohaline (low range of tolerated salinities) and prefer more typical marine salinities (e.g. >30 psu). The megalopa, which migrates to freshwater, is euryhaline, with an optimal growth response in brackish waters (5-25 psu) (Anger 1991). Salinities in the areas where *E. sinensis* has been found range from 0-5 psu in San Francisco Bay (Halat and Resh 1996). It cannot spawn in fresh water and larval growth cannot go to completion in rivers or brackish waters (Anger 1991). Mating and fertilisation in the San Francisco estuary occur in late autumn and winter, generally at salinities of 15- 20 psu. In China, most mating occurs in brackish water (10 – 16 psu) (Hymanson *et al.* 1999). A large increase in the abundance of this species in England coincided with a drought and a large change in the salinity of the estuaries they occupied (Atrill and Thomas 1996).

Methods of Sampling:

Methods of sampling mitten crabs need to differ between adults and juveniles to reflect their different diets and habitats. Adults migrate downstream in late summer to spawn. These crabs are sexually mature. Only juveniles migrate upstream. Juveniles are found in creeks, rivers, and tidal freshwater and brackish marshes and sloughs. Juveniles burrow and occupy burrows but also remain in the subtidal zone.

- Panning (1938) found that because juveniles are mostly vegetarian, capturing them with baited traps didn't work and they had to be excavated from their burrows during low tides. Capturing juveniles in the USA has involved intertidal searches at low tide where all cavities such as burrows and root tunnels were excavated and all debris, driftwood and small puddles were examined. Juveniles were also successfully captured in 'crab condos', submerged artificial structures of PVC tube used for shelter.
- A comparison of trapping techniques by Veldhuizen *et al* (1999) suggested that traditional crab sampling techniques are not very effective for this species due to the change in diet between juveniles and adults, the diversity of habitats occupied, and their escape tendencies. For juvenile crabs she recommends using artificial shelter substrates ("crab condos") made of 12 vertical PVC tubes (6 in long, 2 in diameter) and burrow searches for juveniles in the banks of silty, tidally influenced streams. Crab condos are typically submerged for 48 hours to allow the crabs to enter (Veldhuizen 2000), but significant increases in catch are achieved with longer soak times (3, 5 and 9 days).
- Beach seining for adults was possible in shallow intertidal areas and subtidal areas. Baited traps were not recommended for juvenile mitten crab, or for monitoring and detection programs where adult densities may be very low.
- Various other baited traps, snares and ring nets have also been trailed, with variable success. Ring nets are most successful when densities of crabs are high. The crabs appear to be most active in the two weeks surrounding the full moon.

Impacts

The crab has caused numerous problems in Europe when found in extremely high densities. The burrows that it excavates can destabilise river banks and lead to accelerated bank erosion. The sharp claws of *E. sinensis* cut up commercial fish nets, increasing operating costs of fishing operations. The most widely reported economic impact of mitten crabs in Europe has been damage to commercial fishing nets and the catch when the crabs are caught in high numbers. Because of the severe problems the crab has caused in European waters, *E. sinensis* recently has been listed as a federally injurious species in the United States.

The ban on importing live Chinese mitten crabs to the USA was enacted due to concern over potential damage from its burrows to levees or rice fields in the Central Valley, and because the crab is a second intermediate host of a human parasite, the oriental lung fluke *Paragonimus westermanii* (Cohen and

Carlton 1995). The Chinese mitten crab has been widely reported to be an intermediate host for the Oriental lung fluke, a parasite that uses a snail as its primary host, freshwater crayfish and crabs as intermediate hosts, and a variety of mammals, including humans, as final hosts in its life cycle (Chandler and Read 1961; Lapage 1963). Humans can become infected with the parasite through ingestion. The fluke settles in the lungs and other parts of the body, and can cause significant bronchial or, in cases where it migrates into the brain and/or muscles, neurological illnesses. It is believed that no species of snail that is in the family of the primary host currently occurs in Europe, and no appropriate snail host has been found in the San Francisco Bay-Delta system (Clark *et al.* 1988; Veldhuizen and Stanish 1999). Armand Kuris and Mark Torchin of U. C. Santa Barbara found no parasites of any kind in 25 mitten crabs from San Francisco Bay (A. Kuris, pers. comm., 1995).

The potential ecosystem impacts of large numbers of crabs invading new areas are unknown but authors have often speculated on possible effects to benthic invertebrate communities. There is concern that the crab will consume benthic invertebrates, salmon and trout eggs and may affect other species through direct predation or competition for food resources. In England there is some concern that it may compete with the native crayfish in fresh water (Clarke *et al* 1998). In China and Korea Juvenile mitten crabs have been reported to damage rice crops by consuming the young rice shoots and burrowing in the rice field levees. Since *E. sinensis* often inhabit areas that may contain high levels of contaminants, bioaccumulation of contaminants could also be transferred to predators or humans.

Literature cited

- Anger, K. 1991: Effects of temperature and salinity on the larval development of the Chinese mitten crab *Eriocheir sinensis* (Decapoda: Grapsidae). *Marine Ecology Progress Series* 72: 103-110.
- Attrill, M.J., Thomas, R.M. 1996: Long-term distribution patterns of mobile estuarine invertebrates (Ctenophora, Cnidaria, Crustacea: Decapoda) in relation to hydrological parameters. *Marine Ecology Progress Series* 143: 25-36.
- Chandler, A.C., Read, C.P. 1961. Introduction to parasitology. 10th Edition. New York (NY): John Wiley and Sons.
- Clark, P.F., Rainbow, P.S., Robbins, R.S., Smith, B., Yeomans, E., Thomas, M., Dobson, G. 1998: The alien Chinese mitten crab, *Eriocheir sinensis* (Crustacea: Decapoda: Brachyura), in the Thames catchment. *Journal of the Marine Biological Association of the U.K.* 78: 1215-1221.
- Cohen, A.N., Carlton, J.T. 1995. Nonindigenous Aquatic Species in a United States Estuary: A Case Study of the Biological Invasions of the San Francisco Bay and Delta. U.S. Fish and Wildlife Service, Washington D.C.
- Halat, K.M., Resh, V.H. 1996. The Chinese mitten crab (*Eriocheir sinensis*): implications for the freshwater habitats of the San Francisco Bay and Delta Ecosystem. Sixth International Zebra

- Mussel and Other Aquatic Nuisance Species Conference, Dearborn Michigan, March 1996.
<http://www.ansc.purdue.edu/sgnis/publicat/96Halat.htm>.
- Hieb, K., Veldhuizen, T. 1998. Life history and background information on the Chinese mitten crab. California Department of Fish and Game, Bay-Delta Division. 6 pp.
- Hymanson, Z., Wang, J., Sasaki, T. 1999. Lessons from the home of the Chinese Mitten Crab. *IEP Newsletter* 12(3).
- Ingle R.W. 1986, The Chinese mitten crab *Eriocheir sinensis* (H. Milne Edwards) a contentious immigrant. *The London Naturalist*, 65, 101105.
- Kim, C.H, Hwang, S.G. 1995. The complete larval development of the mitten crab *Eriocheir sinensis* (Decapoda, Brachyura, Grapsidae) reared in the laboratory and a key to the known zoeae of the Varuninae. *Crustaceana* 68(7): 789-812.
- Lapage G. 1963. Animals parasitic in man. Revised Edition. New York (NY): Dover Publications, Inc.
- May, J.T., Brown, L.R. 2001. Chinese mitten crab surveys of San Joaquin River Basin and Suisun Marsh, California, 2000. Open-File Report 01-396 Prepared for the U.S. Geological Survey in Cooperation with the Interagency Ecological Program., Sacramento, California. 25 pp.
- Nepzy, S.J, Leach, J.H. 1973. First records of the Chinese mitten crab, *Eriocheir sinensis*, (Crustacea: Brachyura) from North America. *Journal Fisheries Research Board of Canada* 30 (12): 1909-1910.
- Onken, H 1996. Active and electrogenic absorption of Na^+ and Cl^- across posterior gills of *Eriocheir sinensis*: influence of short term osmotic variations. *Journal of Experimental Biology* 199: 901-910
- Panning, A. 1939. The Chinese mitten crab, Report of the Board of Regents of the Smithsonian Institution (Washington), 3508, 361375.
- Rudnick, D.A., Halat, K.M., Resh, V.H. 2000. Distribution, Ecology and Potential Impacts of the Chinese Mitten Crab (*Eriocheir sinensis*) in San Francisco Bay. University of California, Berkeley.
<http://www.waterresources.ucr.edu>
- SERC 2004. Smithsonian Environmental Research Center, Marine Invasions Research Lab.
http://www.serc.si.edu/labs/marine_invasions/, accessed 29 September 2006.
- Veldhuizen, T.C. 1999. Predictions and predications from a visiting Chinese Mitten Crab expert. *IEP Newsletter* 13(1): 14-15.

Veldhuizen, T.C. 2000. Gear type selection for the Chinese Mitten Crab habitat use study. *IEP Newsletter* 13(1): 10

Veldhuizen, T.C., Stanish, S. 1999. Overview of the life history, distribution, abundance and impacts of the Chinese mitten crab, *Eriocheir sinensis* California Department of Water Resources, Environmental Services Office, Sacramento, California, USA (<http://www.anstaskforce.gov>)

European green crab (*Carcinus maenas*)

General information

The European green crab, *Carcinus maenas*, is native to the Atlantic, Baltic and North Sea coasts of Europe, but has established populations outside this range on the Atlantic and Pacific coasts of North America, in South Africa, and Australia. Green crabs produce planktonic larvae that pass through six developmental stages – a prezoea, 4 zoeal stages, and a megalopa – before metamorphosis to the benthic, juvenile crab phase. The crabs themselves grow through 18 to 20 moult cycles before reaching maximum size and terminal anecysis (Parry *et al.* 1996). In its native range, the green crab can live up to 5 years and males reach a size of 86 mm carapace width. In western North America, adult males can be up to 92 mm carapace width within 2 years (Grosholz and Ruiz 1996).

Timing of reproduction and recruitment

Green crabs mate after the females moult, usually between spring and autumn. In warmer waters, females carry eggs for around four months. Egg-bearing females tend to migrate into deeper water during winter and prezoeae hatch from the eggs predominantly in spring (<http://www.wa.gov/wdfw/fish/ans/greencrab.htm>). The prezoeae pass through four zoeal stages in the plankton before moulting into the megalopal stage. Megalopae appear in early-mid summer and metamorphose and settle into the juvenile crab phase in late summer (Parry *et al.* 1996). The average development time for *C. maenas* larvae varies with temperature. At 10°C development takes around 75 days, and at 25°C it can take as little as 13 days (Parry *et al.* 1996). The timing of settlement is related to the number of months in which water temperatures are below 10°C. In cooler waters, settlement occurs in late summer. In warmer waters, megalopae can begin to settle in late autumn (Yamada *et al.* 2001). Settlement occurs predominantly at night around the time of high tide (Zeng *et al.* 1997).

Habitat and biology

Substratum type

In its native range, the Green Crab, *Carcinus maenas*, occurs on both hard (rocky) and soft intertidal and shallow subtidal habitats in semi-exposed soft-sediment bays (Moksnes 2002). In Europe, eastern North America, Australia and South Africa, green crabs occur in protected embayments and on moderately exposed rocky shores. In western North America green crabs occur only in sheltered embayments and only in soft-sediment environments (Grosholz and Ruiz 1996). A recent survey of the distribution of *C. maenas* in southern Australia found crabs in a range of soft-sediment habitats in low energy embayments. Substratum type, depth and water quality were all poor predictors of its presence and abundance in traps set in these habitats (Thresher *et al.* 2003).

Post larvae (megalopae) settle and metamorphose predominantly in shallow (< 1 m) sheltered or semi-exposed areas that have some form of structured habitat that provides shelter from predators (e.g. seagrass, macroalgae, mussels, shell debris, etc). Small crabs are often found in close proximity to vegetation such as beach grass, reeds, and eelgrass, although they also occur in exposed areas such as bare mud. Larger crabs do not need vegetative cover. In Sweden, young crabs are concentrated in greatest densities within structurally complex habitats, such as mussel beds, shell debris, seagrasses

and filamentous algae. Much smaller densities occur in adjacent sand or mud. Densities of juvenile crabs (2nd – 9th instar) are significantly greater in mussel beds and shell habitats (mean = 206 crabs.m⁻²) than in eelgrass (45 crabs.m⁻²), filamentous green algae (24 crabs.m⁻²) or sand (13 crabs.m⁻²). Settlement of megalopae occurs predominantly to structurally complex habitats such as filamentous algae (231 settlers.m⁻²), eelgrass (159 settlers.m⁻²) and mussel beds (114 settlers.m⁻²), rather than to open sand (4 settlers.m⁻²), but larger animals redistribute themselves among these habitats. Indeed, adult crabs are highly mobile and are capable of foraging over large areas (km to 10's km).

Food preferences

Green crabs are omnivorous. Adult crabs feed predominantly on bivalves (rank = 1), small crustaceans (rank = 2) and smaller numbers of polychaetes and green algae (rank = 3 to 4) (Grosholz and Ruiz 1996).

Physiological tolerances (range and preferences)

Temperature

Carcinus maenas can tolerate a wide range of temperatures. In its native and introduced ranges, animals can tolerate average summer water temperatures of 22°C and average winter temperatures of 0 °C, although adult mortality has been recorded at sustained winter temperatures of 0 °C or below (Cohen *et al.* 1995). Crabs stop moulting and drastically reduce their activity below 10°C, and stop feeding when temperatures are below 7°C (Yamada *et al.* 2001). Successful embryonic development occurs at temperatures between 11 and 25 °C.

Depth

Green crabs are found predominantly in the mid-intertidal zone, between about 1.3 m to 1.7 m above datum, and shallow subtidal, although adults have been recorded as deep as 60 m (Cohen *et al.* 1995). Juveniles (0-1+ age, 1-20 mm carapace width) are found mainly < 1 m water depth (Moksnes 2002). In Bodega Harbour, California, green crabs were caught between +0.7m and 1.4 m above mean lower low-water, with crabs being most abundant at +1.2 m (Grosholz and Ruiz 1995). Parry *et al.* (1996) and Thresher *et al.* (2003) report greatest catches of adult *C. maenas* in water depths < 10 m. However, in Sweden, subadults and adults are found commonly between 0.1 to 20 m depth (occasionally to 60 m).

Salinity

Green crabs tolerate a wide range of salinity, but appear to prefer more saline areas (Proctor 1997). Adults reside in water from 4 psu to 34 psu. Populations breed successfully at salinities down to at least 13 psu, although larvae may only settle at salinities above 17 psu (Cohen *et al.* 1995). Survival of eggs to larval stages occurs at salinities between 26 and 39 psu and larval development may be prevented at < 13 psu (<http://www.wa.gov/wdfw/fish/ans/greencrab.htm>). In the laboratory, adult *Carcinus* prefer salinities of 22-41 psu, but can tolerate maximum salinities of up to 54 psu (Cohen *et al.* 1995).

Methods of sampling

- Standard baited minnow traps (cylindrical with inverted cone entrances of ~ 57 mm) are set near the edge of vegetation or along mud/peat banks, generally far from the low tide drainage channels. Set 5-10 traps with openings perpendicular to the incoming tide with a rock in the trap to hold it in place, and possibly a rock "cradle" made in the substrate to keep the traps from being moved by wave action (http://www.pac.dfo-mpo.gc.ca/ops/fm/shellfish/Green_Crab/FIND.HTML).
- Shore searches along the high tide wrack line where storm driven vegetation accumulates for exuviae of molting crabs. This is most profitable in areas with some vegetation intertidally or subtidally, as molting crabs prefer to have cover available during this vulnerable process (http://www.pac.dfo-mpo.gc.ca/ops/fm/shellfish/Green_Crab/FIND.HTML).
- Yamada *et al.* (2001) compared 4 types of traps for catching *Carcinus*: unbaited pitfall traps, minnow traps, fish traps and box traps deployed in intertidal and shallow subtidal environments. In high intertidal areas, pitfall traps were successful for sampling crabs < 45 mm carapace width. Folding traps and box traps successfully caught crabs > 40 mm. The box traps typically yielded larger catches than other types and caught crabs in their second or third summer.
- Thresher *et al.* (2003) used collapsible box traps (62 cm x 42 cm x 20 cm) to survey populations of *C. maenas* in southern Australia. Traps were typically baited with oily fish and deployed over night for 15-24 hours. Average catch rates from a single overnight set were occasionally as high as 44 crabs.trap⁻¹.

Literature cited

- Cohen, A.N., Carlton, J.T., Fountain, M.C. 1995. Introduction, dispersal and potential impacts of the green crab *Carcinus maenas* in San Francisco Bay, California. *Marine Biology* 122: 225-237.
- Grosholz, E.D., Ruiz, G.M. 1995. Spread and potential impact of the introduced European green crab, *Carcinus maenas*, in central California. *Marine Biology* 122: 239-247.
- Grosholz, E.D., Ruiz, G.M. 1996. Predicting the impact of introduced marine species: lessons from the multiple invasions of the European green crab, *Carcinus maenas*. *Biological Conservation* 78: 59-66.
- Moksnes, P.-O. 2002. The relative importance of habitat-specific settlement, predation and juvenile dispersal for distribution and abundance of young juvenile shore crabs, *Carcinus maenas* L. *Journal of Experimental Marine Biology and Ecology* 271: 41-73.
- Parry, G.D., Lockett, M.M., Crookes, D.P., Coleman, N., Sinclair, M.A. 1996. Review by species, Pages 7-34 in *Mapping and distribution of Sabella spallanzanii in Port Phillip Bay*. Final Report to

Fisheries Research and Development Corporation (FRDC Project 94/164), Department of Conservation and Natural Resources, Victoria, Australia.

Proctor, C. 1997. Spatial correlations between *C. maenas* abundance and elements of the Tasmanian marine benthic community. Page 43, In: Proceedings of the first International Workshop on the Demography, Impacts and Management of Introduced Populations of the European Green Crab, *Carcinus maenas*. Centre for Research on Introduced Marine Pests, Hobart, Tasmania.

Thresher, R., Proctor, C., Ruiz, G., Gurney, R., MacKinnon, C., Walton, W., Rodriguez, L., Nax, N. 2003. Invasion dynamics of the European shore crab, *Carcinus maenas*, in Australia. *Marine Biology* 142: 867-876.

Yamada, S.B., Kalin, A., Hunt, C. 2001. Growth and longevity of the European green crab, *Carcinus maenas*, in the Pacific northwest. (Unpublished manuscript).

Zeng, C., Naylor, E., Abello, P. 1997. Endogenous control of timing of metamorphosis in megalopae of the shore crab *Carcinus maenas*. *Marine Biology* 128: 299-305.

Mediterranean fanworm (*Sabella spallanzanii*)

General information

Sabella spallanzanii is a large (up to 70 cm length) tube-building polychaete that is native to the Mediterranean and Atlantic coasts of Europe. Introduced populations of *S. spallanzanii* have been recorded in Brazil, and in the southern states of Australia (Western Australia, South Australia and Victoria) where it occurs in large densities attached to a variety of substrata. It was first discovered in New Zealand in the Port of Lyttelton in March 2008 during targeted surveillance, where it is currently the subject of a management programme to minimise population growth. A single specimen was subsequently found in the Viaduct Basin, Waitemata Harbour in August 2009, again during targeted surveillance. The worm's tubes are constructed of a tough but flexible material with the outer layer often incorporating deposits of silt and mud. The base of the tube is usually secured to hard substrata such as rocks, jetty pilings or shell fragments (Clapin and Evans 1995), but they may inhabit soft sediments where there are some solid particles (e.g. shell fragments, pebbles) on which the tubes can attach.

Timing of reproduction and recruitment

Sabella spallanzanii is a gonochoric broadcast spawner that releases strings of mucus containing eggs or sperm into the water column (Giangrande *et al.* 2000). Worms attain sexual maturity at around 50 mm length after 6 months of growth. Spawning is thought to occur in autumn and winter in Victoria (Currie *et al.* 2000), although there is some evidence for summer spawning in Western Australia (Clapin and Evans 1995). Females are highly fecund and can produce >50 000 eggs which appear to be fertilised either internally or in situ (Giangrande *et al.* 2000). The fertilised egg masses are negatively buoyant and sink rapidly to the bottom (Giangrande *et al.* 2000). As the egg membrane disappears, free-swimming trochophore larvae emerge. These larval stages have a planktonic life of up to 21 days before they settle to the adult habitat. Settling larvae are gregarious and new recruits often occur in dense clusters. In Victoria, small worms (10-14 cm length) have been recorded in late November (Parry *et al.* 1996). Larvae spend about 2 weeks in the plankton before they settle and metamorphose (CRIMP 2001), but appear to travel only short distances (<20 km) from their parent stock prior to settlement (Parry *et al.* 1996).

Habitat and biology

Substratum type

Sabella spallanzanii grows preferentially in sheltered, nutrient enriched waters that are not subject to waves (Currie *et al.* 2000). In its native range it occurs predominantly on hard substrata and, in Port Phillip Bay, Australia, it is particularly abundant on man-made hard surfaces such as wharf pilings, channel markers, marina piles, etc. It is not common on the hulls of ships (Giangrande *et al.* 2000). Largest densities occur on hard surfaces between 2 m and 7 m depth (Currie *et al.* 2000). In unconsolidated sediments, *Sabella* occurs in areas where suitable attachment substrata (rocks, concrete, wood, steel, bivalves, ascidians, etc) are present and tends to be aggregated in smaller densities. Although it has become established in most subtidal habitats in Port Phillip Bay, Currie *et*

al. (2000) suggest that the larger densities on pilings and artificial hard surfaces reflect a preference for settlement on vertical surfaces.

Feeding

Sabella spallanzanii is a filter feeder that traps suspended food particles using its fan-shaped crown of tentacles. It has apparently been reared in the laboratory on a variety of food, but few details of actual diets are available (Parry *et al.* 1996).

Physiological tolerances (range and preferences)

Temperature

Spawning of *S. spallanzanii* occurs when seawater temperatures range between 11°C and 14°C (Giangrande *et al.* 2000). Optimum conditions for growth are at temperatures of between 10-19°C.

Depth

Sabella spallanzanii has been recorded in water depths of 1 m to 30m (Parry *et al.* 1996). In soft sediments, densities tend to be larger at depths of < 7 m, but decline significantly at greater depth (17 to 22 m) (Currie *et al.* 2000). Densities on hard surfaces in Port Phillip Bay generally increased with depth, but were largest between 2 m and 9 m depth (Currie *et al.* 2000).

Salinity

There are few data on the salinity preferences of *S. spallanzanii*. In its native and introduced ranges, it is abundant in sheltered harbours and ports that are subject to fluctuations in salinity, but most studies have been of populations in relatively saline (> 32 psu) waters.

Literature cited

- Centre for Research on Introduced Marine Pests (CRIMP) 2001. Marine Pest Information Sheet: Giant Fanworm (*Sabella spallanzanii*). CRIMP Infosheet 6, CSIRO Division of Fisheries, Hobart, Australia .
- Clapin, G., Evans, D.R. 1995. The status of the introduced marine fanworm *Sabella spallanzanii* in Western Australia: a preliminary investigation. Centre for Research on Introduced Marine Pests, CSIRO Division of Fisheries, Hobart, Australia, 1-34 (Tech Rep No 2).
- Currie, D.R., McArthur, M.A., Cohen, B.F. 2000. Reproduction and distribution of the invasive European fanworm *Sabella spallanzanii* (Polychaeta: Sabellidae) in Port Phillip Bay, Victoria, Australia. *Marine Biology* 136: 645-656.
- Giangrande, A., Licciano, M., Pagliara, P. 2000. Gametogenesis and larval development in *Sabella spallanzanii* (Polychaeta: Sabellidae) from the Mediterranean Sea. *Marine Biology* 136: 847-861.
- Parry, G.D., Lockett, M.M., Crookes, D.P., Coleman, N., Sinclair, M.A. 1996. Mapping and distribution of *Sabella spallanzanii* in Port Phillip Bay. Final Report to Fisheries Research and

Development Corporation (FRDC Project 94/164), Department of Conservation and Natural Resources, Victoria, Australia.

Aquarium weed (*Caulerpa taxifolia*)

General information

Caulerpa taxifolia is a green single-celled alga (Chlorophyta: order Caulerpales, family Caulerpaceae) native throughout many areas of the tropical Pacific and Caribbean (GISP 2002). It is a popular aquarium plant, and prolonged breeding in aquaria and associated exposure to chemicals and UV light are thought to have produced a hardier strain that differs from native plants genetically and has a higher tolerance to cold water temperatures (Jousson *et al.* 1998). *C. taxifolia* has been introduced to at least three geographical regions outside its native range: the Mediterranean Sea on the coasts of Croatia, France, Italy, Monaco, and Spain, (2) the southern Californian coast near San Diego, and (3) parts of the coasts of New South Wales and South Australia (Meinesz 1999; Campbell and Tebo 2001). However, the “aquarium hypothesis” has been challenged by recent work on the temperature tolerance of native populations in eastern Australia (Chisholm *et al.* 2000; see below).

The basic morphology consists of a thallus with horizontal stolons that give off rhizoids and erect feather-like branches, with pinnately arranged pinnules (GISP 2002). In its native range, *C. taxifolia* occurs mostly in small isolated clumps that reach an average height of 25 cm. In the Mediterranean Sea, however, introduced *C. taxifolia* forms dense “astroturf-like” mats with a height of up to three feet, and up to 213 m of stolon growth and 5,000 emerging fronds per square metre (Meinesz 1999; Anderson and Keppner 2001; Yip 2001). *C. taxifolia* produces several types of secondary metabolites (caulerpenyne) that are toxic to potential competitors or grazers belonging to a range of taxa.

Timing of reproduction and recruitment

Little information exists on the reproduction of *C. taxifolia*. Reproduction in native tropical populations can occur sexually during a short period of the year by synchronised (light intensity) release of anisogamous gametes and formation of zygotes (Zuljevic and Antovic 2000). However, Mediterranean and other introduced populations appear to be able to produce only male gametes, and are thus not capable of sexual reproduction. Therefore, reproduction and dispersal of *C. taxifolia* in the introduced range appear to be solely vegetative (asexual) or by fragmentation (Smith and Walters 1999; Anderson and Keppner 2001; Ramey 2001). *C. taxifolia* is pseudoperennial, with highest rates of stolon growth (up to 8 cm day⁻¹) in summer and autumn, followed by a short resting period from January to April (GISP 2002; Neill 2002). Successful recruitment of dispersed fragments of *C. taxifolia* (as small as 10 mm) can occur throughout the year, but establishment probabilities are highest during summer (Ceccerelli and Cinelli 1999).

Habitat and biology

Substratum type

Caulerpa taxifolia occurs on all types of substrata in both native and introduced range. The alga flourishes equally well on rocky, sandy, mud or clay substrata, both in sheltered and exposed conditions, and in polluted and pristine waters (Meinesz *et al.* 1993; Williams and Grosholz 2002). Dense mats of *C. taxifolia* in the Mediterranean smother other benthic biota, including corals, sponges, and other seaweeds (Meinesz 1999; Neill 2002). *C. taxifolia* can adjust its growth strategy to suit the

type of substratum available. For example, in the San Diego population, upright fronds developed adventitious rhizoids and stolons when lying on sediments, and stolons when entwined within existing algal canopy (Williams and Grosholz 2002).

Food preferences

Caulerpa taxifolia occurs in both polluted and nutrient-poor (e.g. the Mediterranean) habitats (Meinesz 1993). The rhizoid system is used to take up major nutrients from the substratum (Anderson and Keppner 2001), and the extensive biomass of *C. taxifolia* mats acts as a vast nutrient trap (P and N) (Yip 2001). Non-native populations of *C. taxifolia* lack severe nutrient (P and N) limitation (Delgado *et al.* 1996), which may be an important factor enabling it to out-compete native macrophytes.

Physiological tolerances (range and preferences)

Temperature

Mediterranean (introduced) populations of *C. taxifolia* have a temperature range of 9 – 32.5 °C. Some reports claim observation of live plants at 5 °C (Makowka 2000). Survival without growth occurs at temperatures of 10 – 12.5 °C; frond and stolon development commence at 15 and 17.5 °C, respectively, with optimum growth occurring at 25 °C (Gillespie *et al.* 1997; Komatsu *et al.* 1997). The lower temperature tolerance limit is thought to occur only in introduced strains, and to have developed during decades of aquarium-breeding. It is common opinion that *C. taxifolia* within the native range do not grow in water colder than 20 °C (Meinesz and Boudouresque 1996). However, recent research from eastern Australia showed that native populations are able to survive temperatures of 11 °C for a period of four weeks, and that a temperature of 13 °C is sufficient to maintain existing tissue biomass (Chisholm *et al.* 2000). Maximum growth occurs at > 20 °C (Komatsu *et al.* 1997).

Depth

Dense mats of *C. taxifolia* commonly occur at depths of 1 – 30 m, but the alga is known to occur down to a depth of ~ 100 m (Meinesz 1999; Anderson and Keppner 2001; Yip 2001). See “Light” (below) for more information.

Salinity

No specific information on *C. taxifolia*’s salinity tolerance range exists in the literature. Populations in the San Diego area were sampled at 34 psu (Williams and Grosholz 2002). Congeners of *C. taxifolia* are able to grow at salinities of 10 – 40 psu (*C. racemosa*; Carruthers *et al.* 1993) and 15 – 50 psu (*C. lentillifera*; Liao and Cheng 1989).

Light

Stolon and frond growth occur at very low light levels (27 $\mu\text{mol m}^{-2} \text{s}^{-1}$); the optimal light intensity ranges from 88 to 338 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (Mediterranean population; no upper irradiation limit established; Komatsu *et al.* 1997). Other studies report highest growth rates at an irradiance of 75 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (Gillespie *et al.* 1997). *C. taxifolia*’s annual productivity pattern is less affected by fluctuations in light and temperature than what has been reported from endemic seaweeds (Gacia *et al.* 1996).

Photosynthetic assays suggest depth limits for colonisation at 80 m (clear water) and 50 m (turbid water) (Gacia *et al.* 1996). Mediterranean *C. taxifolia*’s maximum photoautotrophic growth limit was

determined as 24 m during winter. Although this correlates reasonably with the distribution of dense populations on the Monaco coastline, the limit is greatly inferior to the maximum reported depth of ~ 100 m, and implies significant heterotrophic carbon acquisition at depths much greater than 24 m (Chisholm and Jaubert 1997).

Methods of sampling

There appears to be no single “best” sampling method for *C. taxifolia* due to its occurrence on a range of substrata. Sampling methods that have been used to detect *Caulerpa* and estimate its abundance include visual transects, video transects, quadrat surveys (hard and soft substrata), grab samples (soft bottom) or sled samples (soft bottom).

Literature cited

- Anderson, L.W.J., Keppner, S. 2001. *Caulerpa taxifolia*: marine algal invader provokes quick response in U.S. water. *Aquatic Nuisance Species Digest* 4(2): 1, 21-23.
- Campbell, T. S., Tebo, M. 2001. Killer algae, *Caulerpa taxifolia*. Institute for Biological Invasions. Invader of the Month. Available online at: <http://invasions.bio.utk.edu/invaders/Caulerpa.html>.
- Carruthers, T.J.B., Walker, D.I., Huisman, J.M. 1993. Culture studies on two morphological types of *Caulerpa* (Chlorophyta) from Perth, Western Australia, with a description of a new species. *Botanica Marina* 36(6): 589-596.
- Chisholm, J.R.M., Jaubert, J.M. 1997. Photoautotrophic metabolism of *Caulerpa taxifolia* (Chlorophyta) in the NW Mediterranean. *Marine Ecology Progress Series* 153: 113-123.
- Chisholm, J.R.M., Marchioretti, M., Jaubert, J.M. 2000. Effect of low water temperature on metabolism and growth of a subtropical strain of *Caulerpa taxifolia* (Chlorophyta). *Marine Ecology Progress Series* 201: 189-198.
- Gacia, E., Rodriguez-Prieto, C., Delgado, O., Ballesteros, E. 1996. Seasonal light and temperature responses of *Caulerpa taxifolia* from the northwestern Mediterranean. *Aquatic Botany* 53(3-4): 215-222.
- Gillespie, R.D., Meinesz, A., Critchley, A.T. 1997. Growth responses of *Caulerpa taxifolia* (Ulvophyceae, Chlorophyta) from the South African aquarist trade. A potential invasive of South African coastal waters. *South African Journal of Botany* 63:480-483.
- GISP 2002. Global Invasive Species Database. Available online at: <http://www.issg.org/database/species/ecology.asp?si=115andfr=1andsts=sss>

- Jousson, O., Pawlowski, J., Zaninetti, L., Meinesz, A., Boudouresque, C.F. 1998. Molecular evidence for the aquarium origin of the green alga *Caulerpa taxifolia* introduced to the Mediterranean Sea. *Marine Ecology Progress Series* 172: 275-280.
- Komatsu, T., Meinesz, A., Buckles, D. 1997. Temperature and light responses of alga *Caulerpa taxifolia* introduced into the Mediterranean Sea. *Marine Ecology Progress Series* 146: 145-153.
- Liao, I.-C., Cheng S.H. 1989. Studies on the salinity tolerance and growth of *Caulerpa lentillifera* at different salinities and substratum types. Proceedings of the 2nd Asian Fisheries Forum, Tokyo. Pp. 399-402.
- Makowka, J. 2000. Monterey Bay National Marine Sanctuary Fact Sheet: *Caulerpa taxifolia*. Report to the Monterey Bay National Marine Sanctuary.
- Meinesz, A. 1999. Killer Algae. Chicago University Press, Illinois. 360 pp.
- Meinesz, A., Boudouresque C.F. 1996. On the origin of *Caulerpa taxifolia* in the Mediterranean Sea. *Sciences de la vie* 319: 603-613.
- Meinesz, A., de Vaugelas, J., Hesse1, B., Mari, A. 1993. Spread of the introduced tropical green alga *Caulerpa taxifolia* in northern Mediterranean waters. *Journal of Applied Phycology* 5: 141-147.
- Neill, K., 2002. *Caulerpa taxifolia*: an accident waiting to happen? *Seafood New Zealand*, March issue, pp. 81-84.
- Ramey, V. 2001. *Caulerpa taxifolia*. Available online at: <http://aquat1.ifas.ufl.edu/seagrant/cautax2.html>.
- Smith, C.M., Walters, L.J. 1999. Fragmentation as a strategy for *Caulerpa* species: fates of fragments and implications for management of an invasive weed. *Marine Ecology* 20: 307-319.
- Williams, S.L., Grosholz, E.D. 2002. Preliminary reports from the *Caulerpa taxifolia* invasion in southern California. *Marine Ecology Progress Series* 233: 307-310.
- Yip, M. 2001. Essay on *Caulerpa taxifolia*. Available online at: <http://www.sbg.ac.at/ipk/avstudio/pierofun/ct/caulerpa.htm>.
- Zuljevic, A., Antolic, B. 2000. Synchronous release of male gametes of *Caulerpa taxifolia* (Caulerpales, Chlorophyta) in the Mediterranean Sea. *Phycologia* 39: 157-159.

Clubbed tunicate (*Styela clava*)

General information

The clubbed tunicate, *Styela clava*, is a solitary ascidian native to the northwest Pacific from the Sea of Okhotsk, southern Siberia, Japan, Korea and the coast of China south to Shanghai (Millar 1970, Cohen 2005). It has a club-shaped body, up to 160 mm long, with a distinct stalk and basal disc with which it attaches to the substratum. Small individuals (<30 mm) may lack a stalk (Lützen 1999). The body wall (test) is leathery and variable in colour (commonly brown-white, yellow-brown or red-brown), with conspicuous tubercles on the upper part and longitudinal ridges on the stalk.

Like all ascidians, *Styela clava* is hermaphroditic (but not self-fertile) and gametes are shed into the water column. The “tadpole” larvae peculiar to ascidians are planktonic and hatch from the eggs after ca 12 hr, although the duration of this period varies with egg size and water temperature (Svane and Young 1989, cited in Bourque *et al.* 2005). The larvae are active for a similar period before settling to the substratum (Holmes 1969, cited in Holmes 1976, Minchin *et al.* 2006). The larvae do not feed and at first tend to swim upwards, though this behaviour later reverses (Millar 1970).

In those species of ascidians that have been studied, life-spans are generally 12-20 months, although some may live for several years (Millar 1970). Minchin *et al.* (2006) stated that the size of individual *Styela clava* (75-180 mm) collected in Ireland “suggests that they were between one and two years old”, although they did not give any reason for this conclusion. Individuals that settled in the Limfjord, Denmark in mid-August grew to 17-48mm by the end of October (Lützen 1999), after which growth ceased during the colder months. Considerable mortality of smaller individuals also occurred during winter. Survivors reached lengths of 50-75 mm by June and became fully mature, spawning in July and August at 75-95 mm. Many small (12-40-mm-long) individuals were also present in early and mid-summer, representing late settlers from the previous year. These, and some of the larger individuals, probably survive a second winter to reach a length of 110-120 mm and reproduce for a second time aged 1.75-2 years old. The lifespan of individuals in southern England was found to be shorter, only rarely exceeding 15 months (Holmes 1969, cited in Lützen 1999). Death may result from senescence, predation or adverse environmental conditions. Reported predators of juvenile *Styela clava* include gastropods (*Mitrella lunata* in eastern North America) and fish (NIMPIS 2002).

The first recorded occurrences of *Styela clava* outside its native range were at Newport Bay (1932) and Elkhorn Slough (1935, a single specimen and no longer present at this site), both in California (Cohen 2005). It subsequently spread along the Pacific coast of North America, north as far as Puget Sound (collected in 1998) and Vancouver Island (collected in 1994) and south as far as Baja California (collected at Ensenada in 2000). On the east coast of North America, it was collected in Massachusetts in 1970, New York in 1972, Connecticut, Maine, New Hampshire and Rhode Island in the 1980s and, more recently, in New Brunswick and Prince Edward Island (1998) (Cohen 2005).

Styela clava was recorded in southwest England in 1953 (Carlisle 1954, Houghton and Millar 1960, both cited in Eno *et al.* 1997) and has since spread to northwest England, southwest Scotland and southern Ireland (collected 1972: Minchin and Duggan 1988). It has also been found in France (1968),

the Netherlands (1974), Denmark (1978-1979), Germany (1997), Portugal (2003) and Spain (2004) (Lützen 1999, Cohen 2005, Davis and Davis 2005).

The first record of *Styela clava* in Australia was in 1972 in Port Phillip Bay, Victoria (Holmes 1976) and in 1977 it was reported from Sydney Harbour, New South Wales (Cohen 2005). It was first recorded in New Zealand in the Viaduct Harbour, Auckland in August 2005 and there appear to be well-established populations in the Waitemata Harbour, Hauraki Gulf and Firth of Thames (Gust *et al.* 2006a). More localised populations have also been found in Lyttelton Port, Lyttelton Marina, Tutukaka and Opuia Marinas (Northland) (Gust *et al.* 2006a and b) and Nelson Port (Morrisey *et al.* 2006). A population was discovered in Port Otago in February 2009.

Timing of reproduction and recruitment

Reproduction is usually restricted to warmer seasons in ascidians living in temperate and cold seas (Millar 1970). Holmes (1969, cited in Holmes 1976) reported that *Styela clava* bred throughout all but the coldest 2-3 months in southern England, with a marked peak of settlement in mid-late summer (late July-early September). A similar pattern of settlement was observed in the Limfjord, Denmark (Lützen and Sørensen 1993, cited in Lützen 1999). Monthly sampling of *S. clava* in southern Ireland (Parker *et al.* 1999) showed gametogenesis (presence of ripe gametes in the gonads) from February-November, with a peak in August-October, and spawning in September-October (when average water temperatures were 15.2°C (± 0.4 SD) – 14.1°C (± 1.3 SD)).

Spawning in ascidians generally occurs in response to a period of light following a period of darkness (Svane and Young 1989, cited in Bourque *et al.* 2005). The rapidity of response to this period of light varies among species and, therefore, not all species spawn at the same time of day. Time of spawning may also vary among populations of the same species from different locations (Bourque *et al.* 2005). In *Styela plicata*, the duration of the light period required to stimulate spawning decreases with increase in the preceding period of darkness (West and Lambert 1976, cited in Bourque *et al.* 2005). Light intensity may also affect the duration of the light period prior to spawning (Forward *et al.* 2000, cited in Bourque *et al.* 2005). Bourque *et al.* (2005) found that concentrations of larvae of *Styela clava* in the upper 1-m of the water column at a field location in Prince Edward Island, eastern Canada, peaked around noon. They pointed out, however, that timing of peak concentrations of larvae may vary among locations and over time at the same location, in response to factors such as day-length, water temperature and light intensity. Cohen 2005 and ISSG Global Invasive Species Database 2006 indicate that *Styela clava* is only able to spawn at water temperatures above 15°C and salinities above 25-26 psu (no sources are given for this information).

Larvae of *Styela clava* do not usually travel more than a few centimetres by active swimming (Minchin *et al.* 2006). Consequently they tend to congregate close to the parent population, although they can be passively dispersed over distances covered by 1-2 tidal excursions (equivalent to the duration of the larval period). Larvae are negatively buoyant but negatively geotactic and positively phototactic, particular at higher hydrostatic pressures, and consequently tend to settle near the water surface (Davis 1997, cited in Minchin *et al.* 2006). Suitable conditions for establishment occur in sheltered localities with salinities of >22 psu and temperatures $\geq 16^\circ\text{C}$ for several weeks (Minchin *et al.* 2006). Individuals apparently reach maturity at 3-10 months (Cohen 2005).

Habitat and biology

Styela clava occurs in low wave-energy environments and sheltered embayments from the upper sublittoral zone to at least 25 m depth (ISSG Global Invasive Species Database 2006). It is especially abundant 10-200 cm below the sea surface (Lützen 1999), and the fact that it has been recorded up to 30 cm above the level of extreme low water of spring tides in southern England (Holmes and Coughlan 1975, cited by Lützen 1999) suggests that it is able to withstand a degree of regular exposure to air. It can apparently survive for up to 3 days out of water under cool, damp conditions (Lützen and Sørensen 1993, cited in Minchin *et al.* 2006). Based on a survey of the distribution of *S. clava* in harbours of the Southern Californian Bight, Lambert and Lambert (2003) noted that the species was consistently more abundant closer to the entrances to bays, where water currents were stronger and that it differed from *S. plicata* in this respect.

Substratum type

Natural substrata for attachment of *Styela clava* include rocks, the blades of macroalgae and the shells of live and dead bivalves (Lützen 1999, NIMPIS 2002, Bourque *et al.* 2005). *S. clava* is also found on a range of artificial structures, including floating pontoons, tyre fenders, vessels, buoys and anchors, and diverse materials, including concrete, cement, wood, ropes and the steel or fibreglass hulls of vessel (Bourque *et al.* 2005, Gust *et al.* 2005, 2006a, ISSG Global Invasive Species Database 2006, Minchin *et al.* 2006). In a survey of harbours in southern California, Fay and Johnston (1971, cited in Lambert and Lambert 2003) recorded *Styela clava* only on floats and pilings and not on any natural substrata.

According to Holmes (1976), *Styela clava* colonises only those surfaces bearing a well-developed epibiota. It can attach to larger individuals of its own species and individual *S. clava* may be extensively fouled with smaller tunicates of their own or other species, algae, sponges, hydroids and bryozoans (Lützen 1999, Cohen 2005, Minchin *et al.* 2006).

On natural substrata, such as rocks or bivalve shells, *Styela clava* is reported to reach population densities of 50-100 m⁻² (Lützen 1999). On artificial substrata, however, much higher densities have been reported (500-1500 m⁻²: Holmes 1976, NIMPIS 2002).

In New Zealand *Styela clava* has been found attached to floating pontoons, wooden pier piles, suspended mooring lines and vessel hulls (Gust *et al.* 2006a). It has also been reported attached to dead bivalve shells on a muddy shore in the Tamaki Estuary, Auckland (Chris Hickey, NIWA, pers. comm.).

Food preferences

Styela clava is a suspension feeder, feeding on suspended, particulate matter, such as phytoplankton, zooplankton and organic detritus, filtered from water pumped through its branchial sac.

Physiological tolerances (range and preferences)

Temperature

Styela clava is reportedly able to tolerate temperatures ranging from –2 to 23°C (Minchin *et al.* 2006). Holmes (1969, cited in Holmes 1976) described a population living in southern England, where water temperature ranged from 2-23°C, and breeding in all but the coldest 2-3 months of the year. On the Pacific coast of North America it has been found at water temperatures ranging from 11-27°C (Cohen 2005). Larvae are able to survive temperatures from 10 - 30°C (Boothroyd *et al.* 2003).

Parker *et al.* (1999) reported no evidence of gametogenesis in individuals sampled in early February in southern Ireland, when the water temperature was 3-4°C, but small numbers of ripe gametes in individuals sampled in the middle of the same month, when the temperature had risen to 8°C. There was evidence that gonad maturation occurred at temperatures below 8°C. Gametogenesis and spawning peaked in August-October, when water temperatures ranged from 14-18°C.

Depth

The reported depth range for *Styela clava* ranges from just above the level of extreme low water of spring tides (in southern England: Holmes and Coughlan 1975, cited by Lützen 1999) to at least 25 m (NIMPIS 2002). Lützen (1999) described *S. clava* as a “predominantly littoral species, which is especially abundant 10-200 cm below the sea surface in areas without tides or when attached to floating objects....The species may extend to depths of 15-25 m...but a record of 40 m depth...is probably exceptional”.

Salinity

Styela clava appears to avoid areas with estuarine conditions (Lützen 1999). Sims (1984, cited in Lützen 1999) found that Californian specimens showed poor vital functions after 3-d immersion in 26.5 psu seawater. This corresponds with Lambert and Lambert’s (2003) observation of die-offs of *S. clava* on floating structures in southern California after heavy rain (followed by rapid recolonisation). They also cited an earlier study (MacGinitie 1939) in the same area that found complete mortality of *S. clava* below a sharp halocline that formed at a depth of ca 2.2 m following heavy rain. Below this depth there was no evidence of any mortality. Individuals can, however, survive shorter periods of salinity as low as 8 psu, presumably by closing their siphons (Sims 1984, cited in Lützen 1999).

Other populations of *Styela clava* may be more tolerant of lower salinities than those studied in California. In the eastern Limfjord (Denmark), populations exist in salinities averaging 26-28 psu, with decreases to <20 psu for periods of several days (Lützen 1999). Individuals experimentally exposed to stepwise decreases in salinity from 31-18 psu showed >50% survival for 40 d (at 12°C) and 50% survival when the salinity was further reduced to 16 psu (Lützen and Sørensen 1993, cited in Lützen 1999). Lützen (1999) cited a report that larvae of *S. clava* from the Sea of Japan were able to complete metamorphosis at salinities of 20-32 psu, but that <18 psu was “deleterious” (no definition given). Cohen (2005) stated that adult *S. clava* die in salinities <10 psu, but did not give a source for this information.

In summary, salinity tolerance of adults and larvae appears to extend as low as 18 psu for extended periods (and much lower for short periods), but may be dependent on the salinity regime to which the population has previously been exposed.

Route of introduction

Styela clava may have reached the Pacific coast of North America as fouling on ships' hulls, but it may also have been introduced as fouling on imported live oysters (Cohen 2005). It is known to occur on oysters (*Crassostrea gigas*) in Japanese oyster farms, and oysters from Japanese farms were transplanted to Elkhorn Slough (California) in 1929-1934, roughly coincident with its date of first detection in California (1932). From Elkhorn Slough it could have been transported to other parts of California as fouling on coastal shipping or via further transfer of oyster stock (including its recent appearance in Humboldt Bay: Cohen 2005).

The introduction of *Styela clava* to southern England is commonly ascribed to fouling on naval vessels returning from the Korean War in 1952 (Minchin and Duggan 1988, cited in Minchin *et al.* 2006), having acquired fouling in the Yellow Sea. It is likely to have spread from the original site of introduction to other parts of the United Kingdom and continental Europe on coastal shipping or, locally, by dispersal of eggs and larvae (Lützen 1999). It has also been suggested that *S. clava* reached the Danish coast, where it was first recorded on an oyster bed in the Limfjord, attached to oysters imported from the English Channel and re-laid in the Limfjord (Lützen 1999). Oyster spat imported from Japan in the 1970s, or transplanted within the English Channel region, may have contributed to the establishment of Dutch and French populations (Lützen 1999).

Given the distances involved, the introduction of *Styela clava* to Australia and New Zealand is likely to have occurred via fouling on ships' hulls, either from its native range or from introduced populations in Europe or North America. In view of the disjunct distribution of *S. clava* in New Zealand's North and South Islands, several inoculation events may have occurred (Gust *et al.* 2006a). Research is currently underway to determine the genetic relationships among populations of *S. clava* in New Zealand.

Minchin *et al.* (2006) noted that *S. clava* tend to be stripped from ships' hulls at speeds above ca 5 kt, unless they occur in more protected habitats such as sea-chests, thruster tubes, or in the lee of stabilisers and other structures on the hull. Lützen (1999) also described *S. clava* as rheophobic (i.e. avoiding strong currents), reducing the likelihood of individuals surviving as fouling on exposed parts of the hulls of rapid vessels in continuous service. Attachment to drifting macroalgae provides another potential means of dispersal. Lützen (1999) stated that fronds of *Sargassum muticum* (a macroalga introduced to Europe from Asia in the early 1970s) with *Styela clava* attached are often washed up on shores in the Limfjord. Fronds become detached from their holdfasts towards the end of the growth cycle and can float for "considerable distances".

Davis and Davis (2004) suggested that a combination of transport mechanisms, including translocation on oyster shell, dispersal on flotsam such as drift macroalgae, fouling on vessel hulls, transport of eggs and larvae in ballast water, and fouling of sea-chests are probably required to explain the present distribution of *S. clava*. Davis (2005) suggested that sea-chests were potentially of greatest importance

because they offer a means of transport for established colonies of individuals, and translocated colonies are more likely to establish new populations than a single inoculum of larvae.

Slow-moving and towed vessels are particularly likely mechanisms of introduction, because of the reduced likelihood of individuals being removed from the hull by water currents during transit. Such vessels may also spend longer periods moored in ports of origin and destination than vessels in continuous service. Specimens of *S. clava* found on vessels in New Zealand have been on a tug (Lyttelton), recreational launches and yachts (Auckland, including one that subsequently travelled to Waikawa Marina, Picton, where it was found to harbour a single individual) and fishing vessels (Nelson) that had been berthed for long periods of time (possibly months in one case, years in another). Of these, recreational vessels are perhaps the most likely to have been the vector of inoculation in the ports where they were found, as the other types of vessel tend to spend most of their time in their home port.

Methods of sampling

- Lambert and Lambert (2003) sampled harbours by examining the sides and bottom edges of pontoons and vessels in marinas, manually removing clumps of fouling organisms to arms' depth, and recovering 5-m long ropes deployed 4 years previously.
- Minchin *et al.* (2006) sampled floating pontoons, supporting piles and quay walls by feeling for specimens by hand, or by scraping adhered biota from the surfaces.
- Gust *et al.* (2005, 2006a,b) employed above-water searches from shore or boat to detect *S. clava* on pontoons, pilings, breakwalls, buoys, heavily-fouled vessels and mooring lines. Submerged ropes were pulled up and examined. Selection of vessels to search was based on a risk-profiling approach based on empirical relationships between level of fouling and probability that the fouling assemblage includes solitary ascidians.
- Gust *et al.* (2005, 2006a,b) also used in-water diver searches of the undersides of pontoons, wharf piles and breakwalls. For safety reasons, and because previous studies had shown that 70% of all *S. clava* detected were found within this depth, searches were confined to the upper 5 m of the water column.
- The probability of *S. clava* being detected by searchers when it is present can be estimated for each type of substratum in a given harbour. These estimates require information on the proportion of the total area of the substrate searched and the sensitivity of the search method under prevailing environmental conditions, particularly water clarity (Gust *et al.* 2006a,b). Sensitivity, the ability of the searchers to detect *S. clava* when present, can be determined by searches for experimentally-deployed mimics of the organism. Details of the methods are given in Gust *et al.* (2006a,b).

Literature cited

- Boothroyd, F.A., MacNair, N.G., Landry, T., Locke, A., Davidson, T.J. 2002. Dealing with an aquatic invader: the clubbed tunicate (*Styela clava*) in Prince Edward Island waters. 19th Annual Meeting of the Aquaculture Association of Canada, 17-20 September 2002, Charlottetown, Prince Edward Island, Canada.
<http://www.aquacultureassociation.ca/ac02/abstracts/FIMF%20non%20indigenous%20species.htm>, accessed 4 August 2006.
- Bourque, D, MacNair, N., LeBlanc, A., Landry, T., Miron, G. 2005. Preliminary study of the diel variation of ascidian larvae concentrations in Prince Edward Island. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2571, 16pp.
- Cohen, Andrew N. 2005 *Guide to the Exotic Species of San Francisco Bay*. San Francisco Estuary Institute, Oakland, California, USA. www.exoticsguide.org, accessed 4 August 2006.
- Davis, M. 2005. Predicting successful invasions of non-indigenous species. American Society of Limnology and Oceanography Summer Meeting 9-24 June 2005, Santiago de Compostela, Spain.
<http://aslo.org/meetings/santiago2005/abstracts/621.htm>, accessed 11 August 2006.
- Davis, M., Davis, M. 2004. The role of man-aided dispersal in the spread of the immigrant *Styela clava* Herdman, 1882. *Journal of Marine Science and Environment* 1: 18-24.
- Davis, M.H, Davis, M.E. 2005. *Styela clava* (Tunicata: Ascidiacea) – a new addition to the fauna of the Portuguese coast. *Journal of the Marine Biological Association of the U.K.* 85: 403-404.
- Eno, N.C., Clark, R.A., Sanderson, W.G. 1997. Non-native marine species in British waters: a review and directory. Joint Nature Conservation Committee, Peterborough, United Kingdom, 135pp.
- ISSG Global Invasive Species Database 2006. IUCN/SSC Invasive Species Specialist Group
<http://www.issg.org/database>, accessed 4 August 2006.
- Gust, N., Floerl, O., Inglis, G., Miller, S., Fitridge, I., Hurren, H. 2005. Rapid delimitation survey of *Styela clava* in the Viaduct Harbour and Freemans Bay, Auckland. NIWA Christchurch Client Report No. CHC2005-147, prepared for MAF Biosecurity New Zealand, November 2005, 45pp.
- Gust, N., Inglis, G., Peacock, L., Miller, S., Floerl, O., Hayden, B., Fitridge, I., Hurren, H., Johnston, O. 2006a. Rapid nationwide delimitation surveys for *Styela clava*. NIWA Christchurch Client Report No. CHC2006-024, prepared for MAF Biosecurity New Zealand, February 2006, 81pp.
- Gust, N., Peacock, L., Inglis, G., Miller, S., Floerl, O., Woods, C., Anderson, O. 2006b. Delimitation surveys for *Styela clava* at six locations. NIWA Christchurch Client Report No. CHC2006-125, prepared for MAF Biosecurity New Zealand, August 2006, 53pp.

- Holmes, N. 1976. Occurrence of the ascidian *Styela clava* Herdman in Hobsons Bay, Victoria: a new record for the southern hemisphere. *Proceedings of the Royal Society of Victoria* 88: 115-116.
- Lambert, C.C., Lambert, G. 2003. Persistence and differential distribution of nonindigenous ascidians in harbors of the Southern Californian Bight. *Marine Ecology Progress Series* 259: 145-161.
- Lützen, J. 1999. *Styela clava* Herdman (Urochordata, Ascidiacea), a successful immigrant to north west Europe: ecology, propagation and chronology of spread. *Helgoländer Meeresuntersuchungen* 52: 383-391.
- Millar, R.H. 1970. British ascidians. Synopses of the British Fauna No. 1, The Linnean Society of London/Academic Press, London, 92pp.
- Minchin, D., Davis, M.H., Davis, M.E. 2006. Spread of the Asian tunicate *Styela clava* Herdman 1882 to the east and south-west coasts of Ireland. *Aquatic Invasions* 1: 91-96.
- Minchin, D., Duggan, C.B. 1988. The distribution of the exotic ascidian, *Styela clava* Herdman, in Cork Harbour. *Irish Naturalists Journal* 22: 388-393.
- Morrissey, D., Bradley, A., Brown, S., Cairney, D., Davey, N., Peacock, L., Rodgers, K. 2006. Rapid survey for *Styela clava* in the Slipway Basin, Nelson Port. NIWA Nelson Client Report No. NEL2006-009, prepared for MAF Biosecurity New Zealand, September 2006, 16pp.
- NIMPIS 2002. *Styela clava* species summary. National Introduced Marine Pest Information System. Hewitt, C.L., Martin, R.B., Sliwa, C., McEnnulty, F.R., Murphy, N.E., Jones, T., Cooper, S (Eds). Web publication <http://crimp.marine.csiro.au/nimpis>, accessed 4 August 2006.
- Parker, L.E., Culloty, S., O’Riordan, R.M., Kelleher, B., Steele, S., Van der Velde, G. 1999. Preliminary study on the gonad development of the exotic ascidian *Styela clava* in Cork Harbour, Ireland. *Journal of the Marine Biological Association of the U.K.* 79: 1141-1142.

APPENDIX 3. EXPERTS CONTRACTED TO REVIEW THE HABITAT SUMMARIES AND SAMPLING METHODS FOR THE TARGET SPECIES

Species	Expert	Affiliation
<i>Asterias amurensis</i>	Greg Parry	Marine and Freshwater Resources Institute, PO Box 114, Queenscliff 3225, Australia
	Craig Johnson	School of Zoology, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, GPO Box 252-05, Hobart TAS 7001, Australia
<i>Sabella spallanzanii</i>	Greg Parry	Marine and Freshwater Resources Institute, PO Box 114, Queenscliff 3225, Australia
	Adriana Giangrande	Dipartimento de Biologia, Stazione de Biologia Marina, Laboratorio de Zoologia, Universita de Lecce, I-73100 Lecce, Italy
<i>Potamocorbula amurensis</i>	Jan Thompson	US Geological Survey, Reston, VA, USA
	Heather Peterson	California Department of Water Resources, 3251 "S" Street, Sacramento, CA 95816, USA
<i>Carcinus maenas</i>	Ed Grosholz	Environmental Science and Policy, University of California , One Shields Way , Davis, CA 95616 -8576, USA
	Per-Olav Moksnes	Kristineberg Marine Research Station, SE-450 34 Fiskebäckskil, Sweden
	Sylvia Behrens-Yamada	Department of Zoology, Oregon State University, Corvallis, Oregon 97331-2914, USA
<i>Eriocheir sinensis</i>	Tanya Veldhuisen	California Dept Water Resources, Sacramento, USA
	Leif-Matthias Herborg	University of Newcastle, Dept. Marine Sciences and Coastal Management, Ridley Bldg Newcastle upon Tyne NE1 7RU, UK
	Debra Rudnick	Dept Environmental Science, Policy and Management, University of California, Berkley, USA
<i>Caulerpa taxifolia</i>	Alexandre Meinesz	Laboratoire Environnement Marin Littoral, Equipe d'Accueil "Gestion de la Biodiversité" (EA 3156), Université de Nice-Sophia Antipolis (UNSA), Faculté des Sciences Parc Valrose 06108 Nice Cedex 2, France
	Susan Williams	Director, Bodega Marine Laboratory , P.O. Box 247 , Bodega Bay, CA 94923-0247, USA
<i>Undaria pinnatifida</i>	Wendy Nelson	NIWA, Greta Point, Wellington
	Bob Fletcher	Earth and Environmental Sciences Research Centre, University of Portsmouth, Burnaby Building , King Henry I Street , Portsmouth , PO1 3QL, UK

A4.1 Sample lot register (record of sample lot code allocated to a sample from which a specimen has been collected for submission to MITS).

Surveillance design report for Port Taranaki • 79

A4.2 Image register (record of identity of specimen that has been photographed to aid identification).

TARGET SURVEILLANCE

IMAGE REGISTER

Surveillance round & survey code:

(e.g WINTER08 & SVBLU7)

PORT:

[illegible]

A4.3 Sledding data sheet.

Target surveillance	SLEDDING : 100+ sled tows per port			Port:	
Sled tows = 2 mins @ 2 knots (80-100m) - Please note if shorter/longer			SVL round (e.g. Summer09).		
Sediment type: 1- Sandy mud, 2- Muddy sand, 3- Sand, 4- Sandy gravel, 5- Shelly gravel, 6- Sand fowl	Survey code (e.g. SVBLU8).				
7- Sand reef, 8- Reef, 9- Other (Please state), 10 - Mud.			Boat:		
Habitat type: 1- Seagrass bed, 2- Oyster bed (2.1 = Pacific, 2.2 = Flat oysters), 3- Horse mussels, 4- Scallops,	Recorder:				
5- Large bivalves (5.1 = Cockles, 5.2 = Pipsis, 5.3 = Others), 7 - Algae, 8- Sponge bed, 9- Nothing	MAFBNZ hotline 0800 80 99 66				
Site ID (from map, e.g. SVBLU8001)					
START POINT of tow - If you can access the pre-allocated site, enter "pre-allocated" here (no coordinates required) - If you have to shift a site, record GPS coordinates (incl. all symbols & decimal points)					
END POINT of tow For all sled tows: Record GPS coordinates Include all symbols and decimal points (very important, please do this)					
DATE (day/month/year)					
Sounder depth (m)					
Secchi depth (m)					
Salinity					
Water temp (°C)					
Wind speed (knots)					
Wind direction					
SEDIMENT TYPE (1-10)					
HABITAT TYPE (1-9)					
	No. of individuals & enter (K) if sample is kept				
SEASTARS					
Asterias amurensis (nthin pacific)					
Coscinasterias sp. (11 arm)					
Patiriella sp. (cushion)					
BIVALVES					
Potamocorbula amurensis (asian clam)					
Musculista senhousia (asian date msl)					
Theora lubrica					
WORMS					
Sabella spallanzanii (mediterr fan)					
Chaetopterus sp. (parchmnt.)					
ALGAE					
Caulerpa taxifolia (aquarium wd)					
Undaria pinnatifida (japan. kelp)					
Codium fragile (brocco wd)					
CRABS					
Carcinus maenas (grn. euro. shore)					
Eriocheir sinensis (chinese mitten)					
Charybdis japonica (asian paddle)					
Pyromaia tuberculata (fire crab)					
Metacarcinus sp. (cancer crab)					
Nectocarcinus integrifrons (red swimmer)					
Macrophthalmus hirtipes (stlk eyed mud)					
Hemigrapsus crenulatus (hairy hand)					
Hemigrapsus sexdentatus (cmn rock)					
Halicarcinus sp. (spider crab)					
Pagurus sp. (hermit)					
Plagusia capensis (red rock)					
Petrolisthes elongatus (porcelain)					
Helice crassa (tunnel mud)					
Notomithrax sp. (deco / cammo)					
Ovalipes catharus (paddle)					
ASCIDIANS					
Styela clava (clubbed sea-squirt)					
Eudistoma elongatum (colonial ascidian)					
Didemnum sp.(colonial ascidian)					
OTHERS (pls note):					
SAMPLE LOT CODE (e.g BLU7100)					
One code per site, include taxa code on pot label					
NOTES: Please record ONLY CORRECT SPECIES NAMES or well known common names, if you're not sure - look it up					

A4.4 Shore search data sheet.

Target surveillance	SHORE SEARCH:		Port:	
MAFBNZ hotline 0800 80 99 66	Target = 25+ sites per port	SVL round:		(e.g. Summer09)
	(10 minute seaches)	Survey code:		(e.g. SVBLU8)
Shore type: 1 - SAND, 2 - SAND & SHELL GRAVEL, 3 - SHELL GRAVEL, 4 - SAND & ROCKS		Recorder:		
5 - ROCKY, 6 - MUD, 7 - MANGROVES, 8 - OTHER (PLEASE STATE)				
Site ID (from map, e.g. SVBLU8001)				
Start point of search (GPS co-ords) include ALL symbols and decimal points (very important, please do this!)				
End point of search (GPS co-ords) include ALL symbols and decimal points (very important, please do this!)				
Date & time				
Location (e.g. name of beach)				
SHORE TYPE (1-8): <i>see above</i>				
Observers names				
Wind speed (knots)				
Wind direction				
Secchi depth (if viewing from boat)				
Sounder depth (if viewing from boat)				
Water temp (if viewing from boat)				
Salinity (if viewing from boat)				
	No. of individuals & enter (K) if sample is kept			
BIVALVES				
Potamocorbula amurensis (asian clam)				
Musculista senhousia (asian date msl)				
WORMS				
Chaetopterus (parchmnt.)				
ALGAE				
Caulerpa taxifolia (aquarium w/d)				
Undaria pinnatifida (japan. kelp)				
Codium fragile (brocco w/d)				
CRABS				
Carcinus maenas (grn. euro. shore)				
Eriocheir sinensis (chinese mitten)				
Charybdis japonica (asian paddle)				
Pyromaia tuberculata (fire crab)				
Nectocarcinus integrifrons (red swimmer)				
Metacarcinus sp. (cancer crab)				
Macrophthalmus hirtipes (stlk eyed mud)				
Hemigrapsus crenulatus (hairy hand)				
Hemigrapsus sexdentatus (cmn rock)				
Halicarcinus (spider crab)				
Pagurus sp. (hermit)				
Plagusia capensis (red rock)				
Petrolisthes elongatus (porcelain)				
Helice crassa (tunnel mud)				
Notomithrax sp. (deco / cammo)				
Ovalipes catharus (paddle)				
ASCIDIANS				
Styela clava (clubbed sea-squirt)				
Eudistoma elongatum (colonial ascidian)				
Didemnum sp. (colonial ascidian)				
OTHERS (pls note):				
SAMPLE LOT NO. (e.g LYT546) include taxa code on pot label				
NOTES: Please record <u>ONLY CORRECT SPECIES</u> <u> NAMES</u> or well known common names, if you're not sure look it up				

A4.5 Sample record (record of taxa present in each sample collected for submission to MITS).

[illegible]

A4.6 Crab and starfish trapping data sheet (also used for crab condos).

TARGET SURVEILLANCE:		CRAB & STARFISH TRAPPING		MAFBNZ hotline 0800 80 99 66				PORT:		
SVL round:		24 HR SOAKS =		Crab trap (CRBTP) lines = 3 traps to each line (minimum 60 CRBTP lines per port)				BOAT:		
(e.g. SUMMER09)				Starfish trap (STFTP) lines = 2 traps to each line (minimum 20 STFTP lines per port)				RECORDER:		
Survey code:		72 + HR SOAKS =		Crab CONDO lines = 3 traps to each line (as many as possible, min 8 CONDO lines per port)				Record only CORRECT SPECIES NAMES or well known common names, if you're not sure - look it up		
(e.g. SVBLU8)										
Site ID	GPS co-ordinates (if you are NOT at pre-allocated site)	SOUNDER & SECCHI DEPTH (when traps deployed)	DATE & TIME IN (day / month)	DATE & TIME OUT (day / month)	Environmental data (Include SPEED and DIRECTION for wind)	TRAP TYPE (CRBTP, STFTP or CONDO)	TRAP NO. (a, b, c or X if no trap)	CONTENTS OF TRAP * ENTER (K) NEXT TO ORGANISM IF KEPT *	SAMPLE LOT NO. Assign only ONE Sample Lot No. per trap. Include taxa code on pot label (e.g. LYT546)	OTHER NOTES If you can't get to pre-allocated site, include reason here too
(from map, e.g. SVBLU8001)	IMPORTANT: include ALL symbols & decimal points (e.g. for latitude: 36° 42.887'S or 36° 42' 34.778"S)	Sounder depth	/	/	Salinity					
					Water temp					
		Secchi depth	:	:	Wind					
		Sounder depth	/	/	Salinity					
					Water temp					
		Secchi depth	:	:	Wind					
		Sounder depth	/	/	Salinity					
					Water temp					
		Secchi depth	:	:	Wind					
		Sounder depth	/	/	Salinity					
					Water temp					
		Secchi depth	:	:	Wind					

A4.7 Diver search data sheet.

TARGET SURVEILLANCE										DIVING										MAFBNZ hotline 0800 80 99 66									
SVL round:		(e.g. Summer09)		Remember: STARTPOINT coordinates only need to be recorded if you are NOT at a pre-allocated site (i.e. if you've shifted a site). If you CAN get to the site, just enter "pre-allocated" (but you still need to record the endpoint)						30+ LOCATIONS																			
Survey code:		(e.g. SVBLU8)								10 piles (or equivalent area (50m) of pontoon, breakwall or other substrate, please state)																			
PORT:																													
BOAT:																													
RECORDER:				Record only CORRECT SPECIES NAMES or well known common names, if you're not sure - look it up						Enter No. of piles the species is observed on (or approx No. per m if breakwall) and enter (K) if sample is kept																			
Site ID (from map, e.g. SVBLU8001)	GPS CO-ORDINATES (including ALL symbols & decimal points (e.g. for latitude: 36° 42.887'S))		DATE (day/month)	Environmental data			Diver names	Transect depth (TD) (2m or 4m or specify) Max depth (MD)	Time & Air IN	Time & Air OUT	TOTAL # OF PILES SURVEYED (or distance of pontoon, breakwall etc)	WORMS		ALGAE		ASCIDIANS		SS		OTHERS		SAMPLE LOT CODE (All samples from the transect = same Sample Lot Code, but enter different taxon codes on pot label)	NOTES If you can't get to pre-allocated site include reason here too						
	START POINT	END POINT		Sounder depth:	Wind speed:	Salinity:						Diver 1:	TD:	MD:	<i>Sabella spallanzanii</i> (Mediterranean fan)	<i>Chaetopterus</i> sp. (parchment)	<i>Caulerpa taxifolia</i> (aquarium weed)	<i>Undaria pinnatifida</i> (Japanese kelp)	<i>Codium fragile</i> (broccoli weed)	<i>Syngaster clavatus</i> (clubbed sea-squirt)	<i>Eudistoma elongatum</i> (colonial ascidian)			<i>Dileptum</i> sp. (colonial ascidian)	<i>Asterias amurensis</i> (thick Pacific sea star)				
			/	Sounder depth:	Wind speed:	Salinity:	Diver 1:	TD:																					
			/	Secchi depth:	Wind Direction:	Water Temp:	Diver 2:	TD:																					
			/	Sounder depth:	Wind speed:	Salinity:	Diver 1:	TD:																					
			/	Secchi depth:	Wind Direction:	Water Temp:	Diver 2:	TD:																					
			/	Sounder depth:	Wind speed:	Salinity:	Diver 1:	TD:																					
			/	Secchi depth:	Wind Direction:	Water Temp:	Diver 2:	TD:																					
			/	Sounder depth:	Wind speed:	Salinity:	Diver 1:	TD:																					
			/	Secchi depth:	Wind Direction:	Water Temp:	Diver 2:	TD:																					