Derwent Estuary Introduced Marine & intertidal Species

Review of distribution, issues, recent actions & management options

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Derwent Estuary Program

The Derwent Estuary Program (DEP) is a regional partnership between local governments, the Tasmanian state government, commercial and industrial enterprises, and community-based groups to restore and promote our estuary. The DEP was established in 1999 and has been nationally recognised for excellence in coordinating initiatives to reduce water pollution, conserve habitats and species, monitor river health and promote greater use and enjoyment of the foreshore. Our major sponsors include: Brighton, Clarence, Derwent Valley, Glenorchy, Hobart and Kingborough councils, the Tasmanian state government, Hobart Water, Hobart Ports Corporation, Norske Skog Boyer and Nyrstar Hobart Smelter.

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INTRODUCTION

The following document is a review of current knowledge of introduced marine and intertidal species occurring in the Derwent Estuary. The lead agency for the management of marine pests in Tasmania is DPIW. This document is intended to provide an overview of current and potential issues and what management options are presently available for introduced marine and intertidal species, and those having recognition as ‘marine pests’. The review has drawn heavily from the research undertaken by CSIRO, University of Tasmania, consultants (notably Aquenal) and others.

There is a need for more research into management objectives, and appropriate control/eradication options where necessary. It is intended that this document will assist the Derwent Estuary Program engage in discussion with DPIW, key researchers and stakeholders to enable the development of a ‘priority action plant’ for introduced marine and intertidal species management in the Derwent Estuary. A priority action plan will hopefully assist in drawing support for the necessary work of preventing new marine pest infestations to the Derwent Estuary, preventing translocation of existing pests, establishing appropriate an achievable objectives for the control/eradication of existing pests, research into and implementation of effective control/eradication options, and the creation and dissemination of educational materials to assist introduced species management.

BACKGROUND

Introduced marine and intertidal species are a particularly insidious form of ecological pollution in that, once established, they can be extremely difficult – often impossible – to eradicate, and can result in severe consequences to the marine environment, aquaculture, commercial and recreational fishing and public health.

Over 70 introduced marine species have been identified in the Derwent Estuary and there are probably many more unrecorded species. For one of these species – the northern Pacific seastar, the Derwent has the dubious reputation of having some of the highest known concentrations in the world. The Derwent is presently considered to be a 'high risk' area in terms of potential transfers of introduced species to other ports. This has economic implications for domestic and international shipping. For example, New Zealand will not permit the discharge of ballast water originating in Tasmanian in New Zealand coastal waters. Vessels that ballasted in Tasmanian waters and wish to enter New Zealand ports must be able to demonstrate that they have carried out a mid-ocean ballast exchange. This requirement has now been extended to include voyages originating in Port Phillip Bay.

Many introduced species appear to have flourished in the Derwent, taking advantage of the disturbed or altered environment. Introduced marine species are believed to have further impacted the ecology of the estuary due to their rapid increase in numbers and propensity to out-compete the native flora and fauna. It is believed that introduced marine species pose a serious threat to indigenous vertebrate and invertebrate species of the Derwent Estuary, particularly the endangered Spotted Handfish, and may also affect human health and public amenity. Temperate southern hemisphere estuaries such as the Derwent are susceptible to marine pest invasions from other temperate areas (e.g. northern Pacific and New Zealand) as they provide comparable conditions (e.g. temperatures) for these species to thrive, but may lack the controls (e.g. predators) to control their populations.

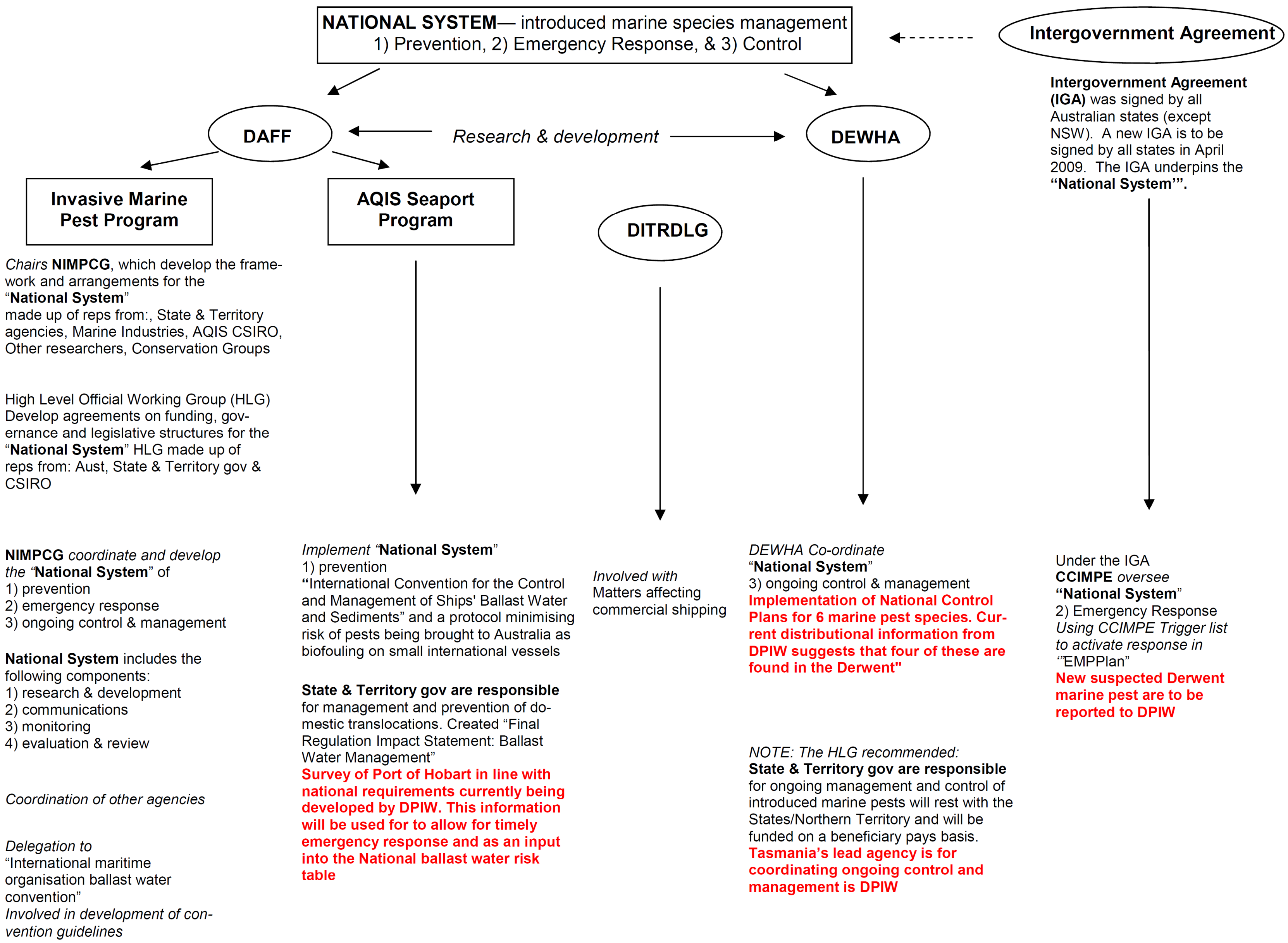
Sources of introduced marine and intertidal species to the Derwent Estuary
Introduced marine and intertidal species may be brought into Australian waters by a range of vectors, including commercial shipping, recreational and fishing vessels, apprehended illegal vessels, aquaculture food and product imports and the aquarium trade. Shipping related vectors are typically ballast water and biofouling. These vectors can also spread, or translocate, these species around Australia.

National System for prevention, emergency response and management of 'marine pests'
A 'National System' has been developed for the management of those species recognised as introduced 'marine pests'. It must be noted that this system contains many elements that apply to all introduced marine and intertidal species (notably the prevention and emergency response to new introduction). The current structure for implementing the National System has been summarised in **Figure 1**. The National System has three major components:

> *1) Prevention: systems to reduce the risk of introduction and translocation of marine pests (including management arrangements for ballast water and biofouling)*
> *2) Emergency response: a coordinated emergency response to new incursions and translocations, and*
> *3) Ongoing control and management: managing introduced marine pests already in Australia, where eradication is not feasible.*

More information can be found at the Australian Government Department Agriculture, Fisheries and Forestry website (http://www.daff.gov.au/animal-plant-health/pests-diseases-weeds/marine-pests/national-system [cited 2 September 2008]). Different Australian and State Government departments have differing roles relating to marine pests. The following discussion provides a Derwent Estuary perspective.

Figure 1. National approach to marine pest prevention, emergency response and management (acronyms in Appendix 1)



National System for prevention

The prevention of new marine pest introductions and the prevention of translocation of current pests to uninfested areas are managed by different agencies. Prevention systems have been, or are being, developed to reduce the risk of introduction and translocation of introduced marine and intertidal species. These include management of ballast water and biofouling of vessels used for commercial shipping, recreational and commercial fishing, marine aquaculture operations, and the aquarium trade, as well as port, harbour and marina facilities. The Australian Government Department of Agriculture Fisheries and Forestry (DAFF) includes the Australian Quarantine Inspection Service (AQIS), which is runs the “Seaport Program” for the prevention of international sources of marine pest introductions into Australia.

International Ballast Water Convention

Since July 2001, the Australian Government has had in place requirements for the management of internationally sourced ballast water that apply to all ships arriving from overseas. These requirements are implemented through the *Quarantine Act 1908* and are administered by the “Seaports Program” within AQIS. On 27 May 2005, Australia signed the *International Convention for the Control and Management of Ships' Ballast Water and Sediments*. This Convention, developed through the International Maritime Organization, aims to prevent the spread of harmful aquatic organisms by ship's ballast water and sediments. Australia is considering ratification of the Convention (bringing the Convention into force within Australia) as part of the process of developing National Ballast Water Management arrangements.

National Ballast Water Management Arrangements

Through the National System for the Prevention and Management of Marine Pests, the Tasmanian government (through DPIW) is participating with the Australian, Northern Territory and other state governments in the development of nationally consistent ballast water management arrangements. These requirements will be consistent with the international Convention and allow Australia to manage the risk from marine pest introductions from both internationally and domestically sourced ballast water and sediments.

The new national ballast water arrangements will provide for a single set of requirements and single coordinating contact centre. The requirements will be implemented under Australian Government legislation for international ballast water and state/territory legislation for domestic ballast water. The national ballast water requirements are currently being developed. State & Northern Territory governments are responsible for management and prevention of domestic translocations, and have created “Final Regulation Impact Statement for Ballast Water Management (March 2007)”. The impact statement was prepared with public consultation and examines the effect of implementing consistent national ballast water management requirements. It is planned that until permanent on-board ballast water treatment can be adopted, some form of ballast water exchange will be required until at least 2016. The strategy for ballast water exchange in domestic waters will be determined from risks at the various Australian ports. The risks will be assessed via a series of ballast water risk table and algorithms, which will be revised annually through port survey requirements. A survey approach for the port of Hobart, in line with national requirements, is currently being developed by DPIW. The annual survey data will be used to update the National ballast water risk tables (when required) and also enables emergency responses to be in acted when new introduced species are identified.

Biofouling

Biofouling is the accumulation of marine organisms (plants or animals) that attach to objects immersed in salt water (such as vessels' hulls, ropes, anchors and other equipment). The AQIS “Seaport Program” is developing guidelines, voluntary protocols or regulations for managing the marine pest risks from biofouling from vessels arriving from international ports. Voluntary implementation of a protocol to minimise the risks of pests being brought to Australia as biofouling on small international vessels (< 25 m length) has been implemented by AQIS since October 2005.

Localised translocations
The Derwent Estuary poses a high level of risk to other Tasmanian and interstate waters that do not yet have the introduced species that are present here. Localised translocation is very likely unless high risk vectors are managed – a community and industry education strategy may be warranted for the Derwent Estuary.

Emergency Response
An emergency response framework has been developed under an Intergovernmental Agreement comprising a Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE) and a National Management Group (NMG), which has the capability to oversee the response to a marine pest outbreak under the "Australian Emergency Marine Pest Plan" (EMPPlan). This is in Working Draft format (since 2005) and is downloadable from the internet site: http://www.daff.gov.au/animal-plant-health/pests-diseases-weeds/marine-pests/national-system [cited 2-Sept-08].

The decision to activate the EMPPlan is based upon a trigger list of target species (the CCIMPE Trigger List – **Appendix 2**); however, the contingency is available to consider other marine pests that also meet relevant criteria to warrant an emergency response.

Emergency response contact
Suspected new marine pest species in the Derwent Estuary should be reported immediately to the:

***DPIW marine pests hotline ph:* 0408 380 377**

Ongoing management and control
The ongoing management and control element of the National System is coordinated by the Australian Government Department of Environment, Water, Heritage and the Arts (DEWHA). DEWHA intends to assist in the containment or control of introduced marine pests established in Australia. DEWHA contracted the Tasmanian consultancy Aquenal Pty Ltd to create National Control Plans (NCPs) for six marine pest species, four of which occur in the Derwent Estuary. A high level Official Working Group (HLG) made up of representatives from Australian, State and Territory governments and CSIRO Marine Pest section, created recommendations on governance, funding, legislation and stakeholder elements for the "National System" for prevention, emergency response and management of marine pests. The recommendation final report (August 2004) can be downloaded from the internet site: http://www.daff.gov.au/animal-plant-health/pests-diseases-weeds/marine-pests/research-pubs/taskforce [cited 2-Sept-08].

The HLG recommended State & Territory governments are responsible for ongoing management and control of introduced marine pests and that this should be funded on a beneficiary pays basis. Tasmania's lead agency for coordinating ongoing control and management in the Derwent Estuary is DPIW.

Review of Derwent Estuary Introduced Marine Species

Of the 70 introduced species recorded in the Derwent Estuary (**Table 1**), *Asterias amurensis* (northern Pacific seastar), *Gymnodinium catenatum* (toxic dinoflagellate), *Crassostrea gigas* (feral Pacific oyster), *Undaria pinnatifida* (Japanese seaweed 'wakame'), *Patiriella regularis* (New Zealand seastar), *Maoricolpus roseus* (New Zealand screw shell) and *Petrolisthes elongatus* (New Zealand half crab), European clam (*Varicorbula gibba*) are likely to be impacting on the ecology of the environment (Aquenal 2002; MacLeod and Heliodoniotis 2005). These species are widespread or frequently reach high abundances within specific areas of the Derwent Estuary.

Table 1. Introduced and cryptogenic species present in the Derwent estuary *on the basis of the literature review and field survey of Aquenal (2002)

Target Introduced Pests	Common name	Non-target Species	Status
Asterias amurensis	Northern Pacific seastar	***Fishes***	
Undaria pinnatifida	Japanese seaweed	*Salmo trutta*	Introduced
Crassostrea gigas	Pacific oyster	*Oncorhynchus mykiss*	Introduced
Varicorbula gibba	European clam	*Salmo salar*	Introduced
Carcinus maenas	European shore crab	*Grahamina varium*	Cryptogenic
Alexandrium catenella	toxic dinoflagellate	*Grahamina gymnota*	Cryptogenic
Alexandrium tamarense	toxic dinoflagellate	***Bryozoans***	
Gymnodinium catenatum	toxic dinoflagellate	*Watersipora subtorquata*	Introduced
		Membranipora membranacea	Introduced
Non-target Species	**Status**	*Bugula neritina*	Introduced
Molluscs		*Bugula flabellata*	Introduced
Maoricolpus roseus	Introduced	*Bowerbankia gracilis*	Introduced
Venerupis largillierti	Introduced	*Bowerbankia imbricata*	Introduced
Neilo australis	Introduced	*Tricellaria occidentalis*	Introduced
Theora lubrica	Introduced	*Cryptosula pallasiana*	Introduced
Raeta pulchella	Introduced	*Conopeum seurati*	Cryptogenic
Chiton glaucus	Introduced	***Hydroids***	
Echinoderms		*Cordylophora caspia*	Introduced
Patiriella regularis	Introduced	*Ectopleura crocea*	Introduced
Astrostole scabra	Introduced	*Ectopleura dumortieri*	Introduced
Crustaceans		*Bougainvillia muscus*	Introduced
Petrolisthes elongatus	Introduced	*Clytia hemisphaerica*	Cryptogenic
Cancer novaezelandiae	Introduced	*Halecium delicatulum*	Cryptogenic
Halicarcinus innominatus	Introduced	*Obelia dichotoma*	Cryptogenic
Corophium acherusicum	Cryptogenic	*Plumularia setacea*	Cryptogenic
Corophium insidiosum	Cryptogenic	*Sarsia eximia*	Cryptogenic
Caprella acanthogaster	Cryptogenic	*Turritopsis nutricula*	Cryptogenic
Caprella penantis	Cryptogenic	*Gonothyraea loveni*	Cryptogenic
Jassa marmorata	Cryptogenic	***Algae***	
Leptochelia dubia	Cryptogenic	*Codium fragile tomentosoides*	Introduced
Elminius modestus	Cryptogenic	*Schottera nicaeensis*	Introduced
Polychaetes		*Polysiphonia brodiaei*	Introduced
Euchone limnicola	Introduced	*Polysiphonia senticulosa*	Introduced
Myxicola infundibulum	Cryptogenic	*Polysiphonia subtilissima*	Cryptogenic
Ascidians		*Ulva lactuca*	Cryptogenic
Ascidiella aspersa	Introduced	*Ulva rigida*	Cryptogenic
Ciona intestinalis	Introduced	*Ulva stenophylla*	Cryptogenic
Botrylloides leachi	Introduced	*Bryopsis plumosa*	Cryptogenic
Botryllus schlosseri	Introduced	*Antithamnionella ternifolia*	Cryptogenic
		Dictyota dichotoma	Cryptogenic
		Enteromorpha compressa	Cryptogenic
		Hincksia sandriana	Cryptogenic

It is possible to review the ecology, potential management and global distribution of a number of the above listed species from the national introduced marine pest information system website http://www.marine.csiro.au/crimp//nimpis/ [cited 2-Sept-2008]. **Figure 2** indicates those areas of the middle and lower Derwent Estuary surveyed by Aquenal (2002) and those areas of the outer Derwent Estuary covered through literature review within their Hobart port survey. There are at least 70 introduced marine species in the Derwent Estuary (Aquenal 2002).

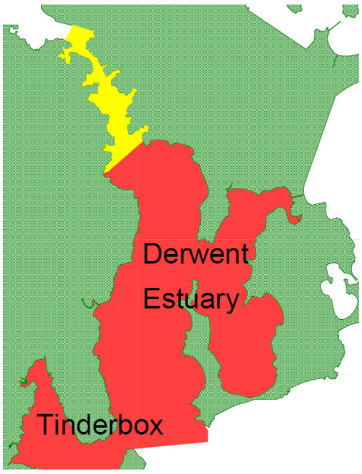


Figure 2. Aquenal summer of 1999/2000 Hobart port survey of the middle and northern-outer estuary areas (Aquenal 2002),

Fourteen of the 70 introduced marine species in the Derwent are likely to occur in soft sandy and muddy sediments (McLeod and Helidoniotis 2005). Numerous locations in the Derwent Estuary with soft sediment substrates have been surveyed for marine pests (see **Figure 3)**.

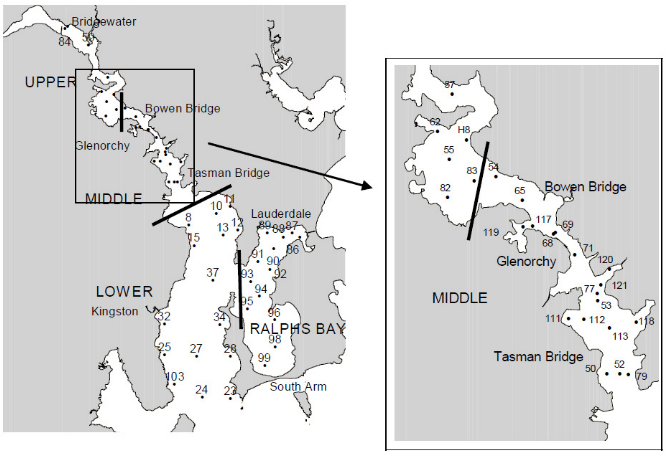


Figure 3. TAFI November 2004 ecological assessment of soft sediment biota in the middle (south of the Bridgewater causeway) and outer estuary regions (including Ralphs Bay) (MacLeod and Helidoniotis 2005).

Physical conditions in the Derwent Estuary make it somewhat susceptible to exotic marine species introductions, these include low current velocities and an abundance of sheltered habitats, which may entrap marine pest larvae (once introduced) and increases the likelihood of larval retention in the estuary environment (Aquenal 2002). Since the estuary contains a wide range of habitats suitable for survival and settlement of larvae, this increases the likelihood of successful colonisation (Aquenal 2002).

The subsequent review in this issues paper will focus upon those introduced species recorded in the Derwent Estuary that currently have National Control Plans (NCPs), such as: northern Pacific seastar

(*Asterias amurensis),* European green crab (*Carcinus maenas*); Japanese seaweed (*Undaria pinnatifida*); and European clam (*Varicorbula gibba*). The NCPs contain a comprehensive review of impacts (environmental, economic, and social), distribution, vectors for translocation, recommendations for the prevention of new infestations, and options for emergency management and ongoing management (based on a review of research and previous control measures). Management frameworks are also outlined, and in some instance management costs have been estimated. It is not the aim of the current paper to reproduce the entire content of the control plans, but instead focus on impacts and management options relevant to the Derwent Estuary.

Some introduced intertidal species, such as rice grass (*Spartina* sp.) were not included in the Aquenal (2002) survey. A Derwent Estuary management plan exists for introduced rice grass (*Spartina* sp.), which occurs in intertidal and supra-tidal areas at several locations in the estuary. *Spartina* eradication from the estuary is an achievable management objective in the Derwent Estuary. This control program has been implemented, and therefore the following review includes *Spartina*. The review also includes comments on those introduced species in the Derwent Estuary having received prior research attention: such as toxic dinoflagellates (notably *Gymnodinium catenatum*), Pacific oyster *(Crassostrea gigas)*, New Zealand half crab *(Petrolisthes elongatus),* New Zealand seastar *(Patiriella regularis)* and New Zealand screw shell *(Maoricolpus roseus)*. To see a more comprehensive review of introduced marine species impacts on the Derwent Estuary, see Aquenal (2002).

Northern Pacific seastar

The northern Pacific seastar (*Asterias amurensis)* is thought to have been introduced to the Derwent Estuary *via* ballast water in the early 1980s. In Tasmania the highest densities are found in the Derwent Estuary, and they have more recently spread to other areas outside of the Derwent. The Derwent is not a closed water way, so some spread may be natural, but other vectors for translocation include ballast and biofouling. The most recent *Asterias* management recommendations are documented in the revised "*Asterias* National Control Plan (NCP) 2008" created by Aquenal Pty Ltd in April 2008 for DEWHA.

Impacts
The following environmental impact review has been taken from the *Asterias* NCP (2008), and specifically relates to the Derwent Estuary

> "Predation by *Asterias* in its native range influences the abundance of a wide range of benthic infauna, including molluscs, ascidians, bryozoans, sponges, crustaceans, polychaetes, fish and echinoderms (Hatanaka and Kosaka 1959; Fukuyama 1994; Fukuyama, A.K., and Oliver 1985).
>
> "The impact of *Asterias* on soft sediment habitats in Tasmania has been the subject of extensive research (Ross *et al.* 2002, 2003a, 2003b, 2004, 2006). Results from experimental manipulations and detailed observations of feeding have demonstrated a large impact of *Asterias* on bivalve populations, particularly those species that live on or just under the sediment surface. *Asterias* appears to be a generalist predator with strong food preferences, but can readily switch to other prey species if the abundance of preferred prey becomes low. At high densities, *Asterias* has the potential to impact a large variety of taxa, with significant and broad effects on soft sediment communities. While *Asterias* also occurs on rocky reef in sheltered habitats, its impacts on these communities remain poorly understood" *Asterias* NCP (2008).

The estimated cost to undertake an investigation of *Asterias* impacts on sheltered rocky reef communities is $100,000 AUD (as of 2008) (estimated costs from *Asterias* NCP 2008). A comparative study between the Derwent Estuary and an *Asterias* free, or lower density, area with sheltered reefs may be warranted.

Asterias has also been implicated as a contributing factor to the decline of the endangered spotted handfish in the Derwent River Estuary (Bruce and Green 1998). *Asterias* have been observed feeding on a stalked ascidians commonly used as a spawning substrate (*Sycozoa* sp.) and it is possible that predatory loss of the ascidian may impact spotted handfish by reducing the available spawning substrate (Bruce and Green 1998). Furthermore, *Asterias*'s predatory behaviour led to suggestions that it also may feed on the slow-moving young of the handfish, and eats the handfishes large benthic egg masses (which *Asterias* will eat in captivity) (Bruce, *et al.* 1997). The impact of *Asterias* on other rare echinoderm species in the Derwent River (e.g. small five armed seastar *Marginaster littoralis*, holothurian *Psolidium ravum*) remains poorly known (Gowlett-Holmes 1999)."

Derwent Estuary *Asterias* distribution and management considerations
The outer Derwent Estuary (south of Tasman Bridge) *Asterias* distribution has been mapped using underwater video transects at depths >3m, Sept –Oct 1999 (Figure 39, in Ling 2000) and the estuary population estimated at that time to be 3 million. The Ling (2000) survey indicated that the highest abundance of *Asterias* occurs around wharfs (>2 individuals/m^2). The next highest abundances (0.05 to 0.03 individuals/m^2) occurred within 1 km wide zones adjacent to the: i) western shoreline, from Tasman Bridge to CrayFish Point (Taroona) and ii) eastern shoreline, from Tasman Bridge to Trywork Point (Droughty Peninsula). Similar distribution density occurs in Ralphs Bay to 10m water depth. Lower densities (0.02 individuals/m^2) occur at the entrance of Ralphs Bay to ~20m water depth, and similar densities occur adjacent to the main Derwent Estuary shoreline to ~15m water depth, along the: i) western shoreline, south of CrayFish Point and ii) eastern shoreline, adjacent to South-arm. At deeper water depths (>15m in the southern section of the outer estuary and >~22 m in the northern

section of the outer estuary), *Asterias* is largely absent (Ling 2000). *Asterias* abundance is thought to be lower in nearshore wave exposed areas of the outer Derwent Estuary (Ling 2000).

Figure 4 indicates *Asterias* distribution observed through soft sediment survey using underwater video (MacLeod and Helidoniotis 2005). *Asterias* has been observed on the seafloor as far upriver as NewNorfolk (Jeff Ross, pers. comm.), where it is living in marine conditions within the saltwater wedge.

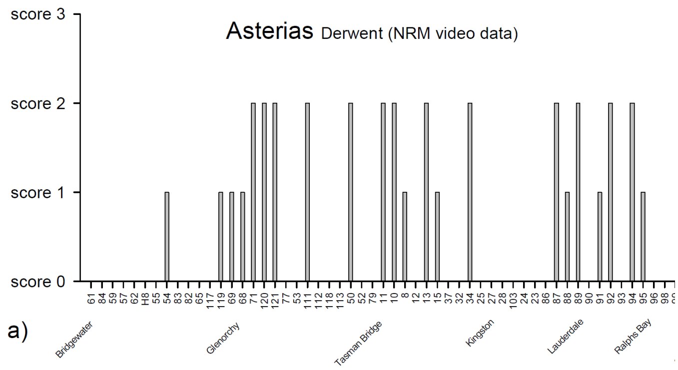


Figure 4. Distribution and abundance of *Asterias* in the Derwent Estuary, Nov. 2004, from video survey. Score 0 = not present, 1=few (1-2 individuals), 3=many (>2 individuals) (MacLeod and Helidoniotis 2005).

Approximately 10% of the Derwent Estuary *Asterias* are found aggregating around wharf structures (occupying ~0.1% of the total estuary area) (Ling 2000). The *Asterias* around the wharfs have been found to have increased gonad/body weight, compared to *Asterias* elsewhere, and are potentially responsible for ~90% of the zygote production in the estuary (Ling 2000). It is hypothesised that by reducing the high density *Asterias* populations found around wharves and jetties in the Derwent Estuary, this can reduce the reproductive output and potentially control the overall population abundance. This is thought to be achieved by reducing the fertilisation success and larval density, which in-turn will cause a decline in recruitment to the adult breeding population. However, the effectiveness of this technique depends on the link between larval abundance and the number of larvae that recruit to the adult population (Bax *et al*. 2006), which is currently unknown (*Asterias* NCP 2008). The *Asterias* NCP (2008) identified the need to improve our understanding of the processes that occur between fertilisation and recruitment to the adult population before the effectiveness of physical removal, or targeted control of seastar aggregations around artificial marine structures can be fully assessed. This research is estimated to cost $100,000 AUD (in 2008) (estimated costs from *Asterias* NCP 2008).

Impact management objectives

Understanding the economic and environmental impact of *Asterias* is vital because it plays a pivotal role in determining whether or not control actions should be pursued. A framework for assessing management decision is presented in the *Asterias* NCP (2008). If the economic and environmental impacts identified warrant a management response, it is imperative that impact management objectives are defined that must either:

1. *Reduce impact within a high value area (e.g. spotted hand fish localities),*
2. *Reduce population size and lower reproduction from high risk 'source' region (e.g. Derwent Estuary wharfs and marinas),*
3. *Contain the pest in a defined geographical range (e.g. reduce Derwent Estuary larval release),*
4. *Long-term reduction in pest abundance.*

Before on ground management is warranted, the *Asterias* NCP (2008) framework requires that the management approach must be effective in reducing impacts and that the benefits of management must exceed the financial cost of implementation. If management is opted on this basis, it is also recommended that monitoring of the effectiveness of the implemented approach should occur so that the outcomes are evaluated and the approach remains adaptive. If *Asterias* eradication is not possible, the objectives of a Derwent Estuary *Asterias* management program need to be developed, before any program of perpetual ongoing control implemented.

Impact management options
Impact management options in the *Asterias* NCP (2008) are defined under three broad categories: *1) Direct targeting of Asterias, 2) Habitat management, and 3) Impact mitigation* (discussed below). A summary of the efficacy and feasibility of currently available management options is provided in **Appendix 3.** However, some options have not been included, but may still warrant further discussion (e.g. chemical application (such as quicklime) in limited geographic areas (see Goggin 1998) like the Hobart wharfs). It is also noted in the *Asterias* NCP (2008) that a combination of options may be the most desirable approach. Some comments on the management options in the Derwent are as follows:

<u>1) Direct targeting of *Asterias*</u>

Physical removal

Different physical removal methods include trapping, diver collection, dredging and purpose built seastar mops. The *Asterias* NCP (2002) identified that dredging is inappropriate in the Derwent due to disturbance to heavy metal contaminated sediments. Considerable effort has been undertaken to trial trapping and diver removal of Asterias from high density areas around wharfs and marinas in the Derwent Estuary.

Trap removal of *Asterias* has been trialled in 1994 and 1996, the Tasmanian Department of Primary Industry and Fisheries as a means of locally reducing seastar numbers. *Asterias* immigrated rapidly and persistently into the trap area. The potential for using traps to control the migration of *Asterias* was tested by trapping at the perimeter of an area which was cleared of *Asterias* by divers. Perimeter trapping, even with traps spaced only 2.5m apart, was not effective in preventing seastars entering the cleared area. Despite these problems, trapping was judged as the best available control method for chronic infestations, regardless of density or depth (*Asterias* NCP 1999). An *Asterias* trapping trial at wharves in the Derwent Estuary, where infestation levels are high, was undertaken by Seatech Diving Service Pty Ltd, titled “Seastar Wars” in 2007. Trialling of a new trap developed by Seatech showed increased trapping of *Asterias*, compared to earlier trialled Whayman traps. However, an independent assessment by Aquenal indicated that neither trap created a detectable fish down pressure on *Asterias* to be considered an effective control option.

Diver removals have so far been largely ineffective as an impact management strategy; although to date they have only been tested on an experimental scale. Diver removal of *Asterias* from around marine structures in the Derwent Estuary has been undertaken previously in 1993 and 2000. Subsequent monitoring of the 2000 diver removal at two wharf sites indicated that after two months the *Asterias* densities had recovered to pre-removal densities at one of the sites, while at the other site the densities had increased but were still slightly lower compared to ‘pre-removal’ surveys. The findings are presented on the CSIRO webpage (http://www.marine.csiro.au/crimp/cleanup/cleanup.htm [cited 4-Sept-08]). Diver removal is viewed as an ineffective control option in-part due to the high costs associated with this approach. It is not considered cost effective for high infestation areas, compared to the use of traps (Andrews *et al.* 1996). For *Asterias* infestations that are sporadic over time and when densities are below 1.5 m^{-2}, diver control may be more appropriate (*Asterias* NCP 2008). Furthermore, it is prohibitively expensive in water depths exceeding 12m, which is potentially an issue at the south eastern and eastern side of the Macquarie Wharf near Sullivans Cove. A cost-benefit analysis may be required to assess the validity of ongoing diver removal.

> *Physical removal (by divers) of Asterias from Hobart wharfs cost estimates from Asterias* NCP (2008) *are:*
> *- Fully funded estimated cost $256,160 / year + monitor at $57,064 / year*
> *- If volunteer based (divers, etc) estimated cost $21,560 / year + monitor at $57,064 / year*

Although seastar mops are not described in the *Asterias* NCP (2008), the method warrants description if applied to high infestations around the Derwent wharfs and marinas. A common seastars mop consists of 12 to 16 large rope yarn brushes, around 1.5m long, attached to a 3m long iron bar, usually deployed from either side of a towing vessel and operated in much the same way as a dredge. Seastars become entangled in brushes, and once bought to the surface can be killed by lowering into troughs containing hot water (*Asterias* NCP 1999).

Maybe seastar mops are appropriate in those areas in the Derwent seaward of wharf infrastructure, but is not feasible beneath wharfs, constantly occupied shipping berths, or in areas where the mop cannot be effectively towed. Seastar mops have been used successfully around marine farms in the northern hemisphere, but a high frequency of use is often applied until population levels are greatly reduced. The potential for sediment disturbance (and heavy metal mobilisation) would warrant investigation if seastar mops were to be used in the Derwent.

The *Asterias* NCP (2008) states that in relation to any physical removal method that “the effectiveness of localised reduction of *Asterias* populations around wharves as a management response is reliant upon the direct link between larval abundance and recruitment. If this link does not exist or is weak, this management approach would be futile.”

Chemical control

Chemical control includes application of chemicals (toxic to *Asterias* or interfering with reproduction) and direct injection of *Asterias* with toxic substances (e.g. formaline copper sulphate, hydrochloric acid and ammonia) (Goggin 1998). The large numbers of *Asterias* in the Derwent makes direct injection a slow and physically difficult and potentially expensive proposition (maximum injection rates are around 140 individuals/hours in high infestation areas (Birkeland and Lucas 1990, in Goggin 1998).

The broad scale application of chemical is also considered an environmentally and socially unacceptable control option; however, if localized use of chemicals were more acceptable the use of them would require a risk analysis. For example, quicklime application to the seafloor has been used to kill *Asterias* in the northern hemisphere (Goggin 1998). A laboratory study into quicklime toxicity to Derwent Estuary *Asterias* indicated that short-term exposure (5 hours) is not sufficient to cause death (Goggin, *unpublished* in Thresher *et al.* 1998, in Goggin 1998), and as such longer term exposure would be required for effectiveness. The effect of quicklime on *Asterias* can last in the sediment for several weeks, and can be either applied in a dispersed manner or deployed in porous bags. Extended exposure to quicklime is expected to cause seastar death within two weeks (Goggin 1998). Such a technique may be applicable around marine structures in the Derwent Estuary; however, quicklime is harmful to other marine organisms (especially crabs, larval crustaceans, fish eggs and adult flatfish, and other echinoderms). If localised quicklime applications were to be trailed, an impact assessment would be required to look at: 1) associated human health issues, 2) the effect on other organisms, 3) the effect on sediment biochemistry (possible redox change) to determine if heavy metal releases would occur from contaminated Derwent Estuary sediments, 4) the overall effectiveness of the technique and 5) social opinions and values.

Chemical manipulation of *Asterias* breeding (reduce/inhibit reproduction, or alter breeding timing) may be a potential option, but would require further research and development. One group of chemical inhibitors are supposedly species-specific (i.e. asterosaponins) (McLoughlin and Bax 1993, in Goggin 1998). and Broadcast application of such chemicals, may not provide adequate dosage, but lacing prey items or baits with species-specific breeding inhibitors may be more appropriate for localized control efforts around Hobart wharfs and marinas (Thresher *et al.* 1998 in Goggin 1998).

Biological control (introduced control, enhancing native predators, and genetic modification)

Research on the impact of a parasitic ciliate *Orchitophyra stellarum* on *Asterias* in Japan has been undertaken (Goggin 1998); however, there are documented warnings against introducing this to Australia as a biological control agent (Byrne *et al.* 1997). Its capacity to control *Asterias* populations remains doubtful, and in addition, its ability to infect other asteroid genera raise serious concerns in relation to potential impacts on non-target species (*Asterias* NCP 2008).

The native seastar *Coscinasterias muricata* may be a natural biological control option, as it has been observed predating on *Asterias* adults (Goggin 1998) and is also likely to compete with *Asterias* for food. Further research efforts are required to determine the significance of native predators (*C. muricata* or others) in controlling *Asterias* (including predators of adults and juveniles) and whether they have the potential to influence *Asterias* population density (*Asterias* NCP 2008). The *Asterias* NCP (2008) assessed research and development into the potential of enhancing native species predation of *Asterias,* and estimated the cost at $300,000 (in 2008) and the overall R& D priority as being very low.

Reducing the reproductive success of *Asterias* through the release of genetic modified seastars has been assessed as a control option (Bax *et al.* 2006). The three techniques were examined but they varied in the effort needed to achieve the removal of a relatively small population in the Derwent estuary. Two of the genetic control options modify the sex ratios of populations (reducing daughters or sons), and the third introduces a lethal gene into the population killing females. The insertion of transgene females in order to create a 'sonless' wild populations appear the most successful genetic modification management option. Modelling studies on the Derwent suggest that populations that have transgene animals with two constructs rapidly became extinct after the insertion of more than 250,000 transgene animals (Bax *et al.* 2006). While daughterless control does not reduce a population easily, it does offer another potential control option if an inducible lethal gene were linked to the genetic construct (Bax *et al.* 2006). This later option has not been modelled or tested. Modelling of a female lethal gene linked to transgene males was shown to be as effective as daughterless control. However, before genetic modification of *Asterias* for pest control could be applied, public concern and legislative restrictions associated with release of genetically manipulated organisms would need to be overcome (*Asterias* NCP 2008).

<u>2) Habitat management</u>

Food reduction

In the Derwent Estuary, dense populations of *Asterias* are associated with wharf and marina structures that provide an abundant source of food, primarily mussels that fall from supporting structures due to wave action (Ling 2000). Food is also thought to be provided from the disposal of boat hull scrapings, and fishing baits around wharfs and marinas. Removing the source of food is one indirect way of reducing *Asterias* abundance and reproductive output. The *Asterias* NCP (2008) acknowledges they may be merit in this approach, but the practicalities and consequences of removing mussels from artificial structures are yet to be considered. The *Asterias* NCP (2008) recommended future research and development into the practicalities of food removal from artificial structures, estimating the R& D cost at $100,000 (in 2008). Changing practices and facilities at wharfs and marinas may also reduce food sources arising from boat maintenance and waste disposal, and may require education and facility upgrades.

Environmental improvement

It had been previously assumed that *Asterias* had preference for poor or disturbed habitats, and that maintaining healthy environments or improving the overall environmental condition of a site may reduce or prevent *Asterias.* The Derwent Estuary is a modified marine environment, and the general improvement of the estuary is an objective of the DEP. Improved understanding of the role of human-mediated disturbance in the invasion process for *Asterias* is crucial for assessing disturbance impacts and management options and actions (*Asterias* NCP 2008).

<u>3) Impact mitigation</u>

Impacts of *Asterias* on commercial, environmental or social values within the Derwent Estuary are moderately well understood (see impacts section above). However, in most instances effective mitigation approaches have not been developed or associated costs estimated.

General considerations

If *Asterias* eradication is not possible from the Derwent, the objectives of a Derwent Estuary *Asterias* management program needs to be developed, before any perpetual ongoing control implemented. The objectives and potential control options should be informed from the *Asterias* NCP 2008, and scientific advice.

Potential management objectives should focus on reducing *Asterias* abundance and/or impact mitigation in high value areas, notably those areas where threatened spotted handfish and echinoderms are present and at risk from *Asterias* predation or habitat modification. It is not clear if this would be best achieved by directly targeting control of *Asterias* at known threatened species sites, or if efforts should concentrate upon the major *Asterias* breeding aggregations (associated with artificial structures in the Derwent).

Physical removal of high density *Asterias* populations associated with artificial structures is a potentially effective control method for reducing adult abundance and subsequent reproductive success. However, further research is required to address some of the key assumptions that underpin the effectiveness of this control strategy, notably understanding the link from *Asterias* fertilization and larval abundance to adult recruitment (*Asterias* NCP 2008). If target control at artificial structures is proven to be an effective control approach, further research and development is required to determine the most appropriate method/or combination of methods to achieve this. There is currently a drive to retest diver removal, although this option has been previously tested.

The Derwent Estuary is an open aquatic system, connected to Storm Bay and the rest of the Tasmanian coastline. Estuarine and ocean circulation will enable a natural rate of *Asterias* emigration beyond the Derwent estuary. This has potentially already occurred with *Asterias* now being found in the D'Encastreaux Channel and along the Tasmanian east coast. This issues paper does not provide a discussion on management options for those areas outside of the Derwent Estuary, where *Asterias* may have already spread. The *Asterias* NCP (2008) identified that the management objectives and options are best presented on a case by case basis. However, management of the species within the Derwent could possibly reduce the natural rate of spread outside of the estuary as well as educate maritime uses of the Derwent on how they can assist in reducing or preventing accidental translocation to areas that are still as yet uncolonised.

Japanese seaweed ‘wakame’

The Japanese seaweed *Undaria pinnatifida* was first found and identified in Tasmania in 1988 on the states east coast. The distribution soon included the outer Derwent Estuary, having been observed at Tinderbox marine reserve in 1997. The establishment of *Undaria* at Tinderbox is not thought to have been through natural dispersion, but instead translocation from the east coast is likely through recreational or commercial boating, or contaminated diving or fishing equipment (Aquenal 2002). *Undaria* grows up to 3m in length, and typically occurs on hard substrates, such as artificial and natural reefs and boat hulls, and can also establish on soft sediments in seagrass communities (information from New Zealand *Undaria* action plan: http://www.biodiversity.govt.nz/pdfs/seas/undaria_action_plan_dec01.pdf [cited 20 October 2008]).

Undaria grows in a wide range of wave exposures from sheltered marinas to the open coast, and extends vertically from the low intertidal to 18 m depth (although it is most common between 1 and 3 m depth), but is unlikely to invade areas with a high fresh water input [Information from New Zealand *Undaria* action plan: http://www.biodiversity.govt.nz/pdfs/seas/undaria_action_plan_dec01.pdf Cited 20 October 2008]. It is typically an annual species with two stages in its life cycle. These are a macroscopic seaweed stage (the sporophyte), usually present through the late winter to early summer months and a microscopic stage (the gametophyte), present during the colder months (information from NIMPIS website: http://www.dpiw.tas.gov.au/inter.nsf/WebPages/ALIR-4Z56E6?open [cited 8-Sept-08]). The most recent *Undaria* management recommendations are documented in the revised “*Undaria* National Control Plan (NCP) 2008” created by Aquenal Pty Ltd in April 2008 for DEWHA.

Impacts

Disturbance plays an important role in the invasion ecology of *Undaria* in Tasmania. Removal of native algal canopies by storms damage, sea urchin grazing or human activities, results in the formation of dense stands of *Undaria*. In the absence of disturbance, native seaweed canopies are resistant to *Undaria* invasion (*Undaria* NCP 2008). Observations of *Undaria* infestations in New Zealand indicate that small scale disturbance and *Undaria* colonisation can be subsequently outcompeted and replaced by surrounding native algal species. However, on larger disturbed areas, such as sea-urchin barrens, native seaweed recovery is much slower or not at all without management intervention. If the observed response of *Undaria* in Tasmania is a general phenomenon, the abundance and subsequent impacts of *Undaria* will be dependent on the frequency, intensity and timing of disturbance (*Undaria* NCP 2008). Disturbances just prior to development of *Undaria* sporophytes are likely to result in the formation of dense *Undaria* populations (Valentine and Johnston 2003). Other potential impacts of *Undaria* that remain poorly understood include effects on nutrient cycling and trophic dynamics and reduced diversity and abundance of native fauna associated with a canopy of *Undaria* (Innes 2001, in *Undaria* NCP 2008).

Derwent Estuary *Undaria* distribution and management considerations

The impact of competition between *Undaria* and native macroalgal species (e.g. Giant kelp *Macrocystsis pyrifera*) also remain unknown (*Undaria* NCP 2008), and it is noteworthy that both these species have overlapping distribution on the western entrance of the Derwent Estuary. The Tinderbox Marine Reserve, at the estuary entrance also has *Undaria* present in the intertidal zone (CRIMP website: http://www.marine.csiro.au/crimp//nimpis/ [cited 8-Sept-08]). No systematic reef surveys have been undertaken to fully assess its distribution in the estuary.

Undaria may have negative impacts on public amenity for recreational divers, fishermen and shore fossickers around the Derwent Estuary, in areas of sheltered rocky reef and intertidal rock platforms that have the potential to support a dense coverage of *Undaria* (*Undaria* NCP 2008).

Impact management objectives
Understanding the economic and environmental impact of *Undaria* is vital because it plays a pivotal role in determining whether or not control actions should be pursued. A framework for assessing management decision is presented in the *Undaria* NCP (2008). If the economic and environmental impacts identified warrant a management response, it is imperative that impact management objectives are defined. Potential Derwent Estuary objectives may focus on:

1. *Reduce impact within a high value area (e.g. Tinderbox Marine Reserve, and nearby Giant kelp forests),*
2. *Protect and improve natural habitat to reduce potential Undaria establishment.*

Impact management options
Impact management options in the *Undaria* NCP(2008) are defined under three broad categories: *1) Direct targeting of Undaria, 2) Habitat management,* and *3) Impact mitigation* (discussed below). The likely effectiveness and feasibility of impact management will also depend on the spatial extent and density of the target population which will require assessment on a case-by-case basis. To maximise the effectiveness of management activities, control efforts should sensibly target the macroscopic sporophyte prior to development of reproductive tissue (sporophylls). Seasonality is a particularly important issue in relation to *Undaria* management, because it is an annual species that alternates between a macroscopic sporophyte and a microscopic gametophyte.

<u>1) Direct targeting of *Undaria*</u>

Physical removal

The *Undaria* NCP (2008) identified physical removal of *Undaria* populations as the only potentially effective control method currently available for reducing sporophyte abundance and subsequent reproductive success. Physical removal of *Undaria* sporophytes is very labour intensive and only likely to be practical for small-scale (< 1000 m^2) populations (*Undaria* NCP 2008), and as a result should only be undertaken in those areas of high environmental values (e.g., Marine Reserves, and areas of threatened species). The national control plan includes a hypothetical case study for control of a small *Undaria* population (1000 m^2) through manual removal by divers and estimates the cost of this (using 2008 values), note monitoring of the effectiveness of the approach would cost extra:

Physical removal (by divers) of Undaria from 1000 m^2 area
- Fully funded estimated cost $38060 / year
- If volunteer based (divers, etc) estimated cost $9140/ year

Because *Undaria* also has microscopic gametophytes, which remain viable for over 2.5 years after removal of the vegetative sporophyte, small area once-off physical removal efforts have not eliminated this marine pest (*Undaria* NCP (2008)). A longer term 'weeding' approach is required, as undertaken in terrestrial management approaches, combined with efforts to prevent re-inoculation of a site with gametophytes. It is noteworthy that *Undaria* removals were conducted in the Tinderbox Marine Reserve for a number of years, but with limited long term success (A. Morton, *pers. comm.*, 22 October 2008). Steam treatment of hard surfaces, notably boat hulls, is a successful but extremely slow way to kill any microscopic *Undaria* gametophytes that may be present (*Undaria* NCP 2008). However, this may be appropriate when antifouling artificial surfaces, but possibly not on natural substrates where native species will also be impacted.

Biological and Chemical Control

The *Undaria* NCP (2008) also presents other control options, using biological and chemical agents, but neither options are well developed and considerable feasible or appropriate to date.

2) Habitat management

Reduced human pressures (pollution, fishing and climate change)

Some disturbances to native seaweed beds are beyond the scope of control (e.g. storm damage); however, a number of human induced disturbances can lead to loss of native algal cover leading to easier *Undaria* establishment (*Undaria* NCP2008). Anthropogenic causes for reduced native seaweed cover include: pollution (as well as increased sediment loading), fishing pressure, and climate change related ecosystem changes causing increased sea urchin grazing.

Habitat management options can promote healthy native seaweed communities, such as improved catchment environments that will improve water quality run-off into the Derwent Estuary through: preservation of natural urban streams and drainage lines, retaining vegetation buffers around foreshores and catchment drainage, improved stormwater management (e.g., implementing water sensitive urban design) and improving land use practices (herbicide, nutrient and water use). Increased urchin grazing of native seaweeds can lead to the creation of 'urchin barrens', which can be more readily colonized by *Undaria.* Increased urchin abundance (notably *Heliocidaris erythrogramma*) has been linked to fishing pressures (removal of urchin predators) and also combined with climate change related migration of a northern urchin species (*Centrostephanus rodgersii*) into east-coast Tasmanian waters from mainland Australia. Fishing pressures can be reduced from high priority sites through the creation of Marine Reserves (such as Tinderbox Marine Reserve). Expansion of the existing, or creation of new, Marine Reserves may be an appropriate management option to aid in the preservation of Giant kelp, *Macrocystsis pyrifera*, between Tinderbox and Blackmans Bay. Alternately, a 'no take' zone could be established for key urchin predators, such as spiny lobster (*Jasus edwardsii*). A climate change associated increase in urchin numbers may also be mitigated by the protection of key urchin predators. A well established *Macrocystsis* forest is present within the vicinity of the Blackmans Bay Waste Water Treatment Plant (WWTP) effluent outfall, where it is speculated that the nutrients released are beneficial to the *Macrocystsis* at this location. Ongoing management of the Blackmans Bay WWTP outfall and nutrient loadings and concentration should be mindful of this, so as to retain conditions that favour *Macrocystsis* and prevent it's replace with *Undaria.*

The *Undaria* NCP (2008) recognizes that reducing anthropogenic habitat disturbance may assist in preventing *Undaria* establishment, it is uncertain if this approach would enable already heavily infested locations (such as Tinderbox Marine Reserve) to recover native algal cover without other management intervention.

Restoring native algal cover

Historically the distribution of native Giant Kelp (*Macrocystsis pyrifera*) was greater within the Derwent Estuary than today. With the loss of this habitat type from some areas of the estuary, it is possible that *Undaria* may more readily establish, depending upon presence of other native algal cover. The re-establishment of *Macrocystsis* to other areas of the Derwent Estuary has been trialed (Seacare, website: http://www.seacare.org.au/html/derwent_map.htm [cited 9-Sept-08]), but has not yet proven to be very successful.

3) Impact mitigation

There has not been a systematic survey of habitats in the Derwent to identify those areas already infested with *Undaria* and those areas that are currently at risk. Recent seafloor substrate mapping by TAFI (Lucieer *et al.* 2007) enables areas of hard-substrate to be identified and outer estuary seagrass communities (which are likely areas of highest risk). Effective mitigation approaches for the Derwent Estuary have not been developed or associated costs estimated.

General considerations
Development of potential *Undaria* management objectives and control options for the Derwent Estuary should be done using information from the *Undaria* NCP 2008, and advice from DPIW and other experts.

There is a need for diver survey data from the Derwent Estuary, to identify the current level of *Undaria* infestation and those habitats at risk of infestation. Potential management objectives should focus on those areas with highest environmental values that are threatened by *Undaria* (e.g. Tinderbox Marine Reserve, Giant Kelp Forests, outer estuary seagrass beds?). A contingency plan for new occurrence in the Derwent Estuary should be created, which indentifies the appropriate response if *Undaria* is found in areas that threaten important natural values.

Undaria has a weed-like ecology, as it opportunistically colonises disturbed habitats where native macroalgal cover is reduced. Anthropogenic pressures should be reduced in order to retain good native macroalgal coverage, through reduced pollution (notably sediments, hyrdocarbons, excessive nutrients, herbicides) and fishing pressure (perhaps establishing 'no-take' areas for spiny lobsters).

In those areas where management intervention is warranted, appropriate techniques and associated risks (of further *Undaria* spread and damage to remnant native macroalgal coverage) would need to be assessed. It is possible that heavy infestations at Tinderbox Marine Reserve warrant management if natural values are under threat, or if this is the principal 'source' area for water current dispersal of *Undaria* into the Derwent Estuary. Typically water currents pass eastward along the Tinderbox Marine Reserve then flow into the Derwent Estuary (CSIRO modeling studies).

Public information should be created to prevent translocation of *Undaria* within and beyond the Derwent Estuary.

European Clam (*Varicorbula gibba*)

The northern European Clam (*Varicorbula gibba*) is thought to have been introduced to the Derwent Estuary via domestic shipping from Port Phillip Bay in 1996. The most recent *Varicorbula* management recommendations are documented in the revised "*Varicorbula* National Control Plan (NCP) 2008" created by Aquenal Pty Ltd in April 2008 for DEWHA. *Varicorbula* is a small bivalve (15-20mm maximum size). It is a shallow burrower that inhabits thick muddy sand, with a preference for higher organic levels. It has the ability to attach to gravel and stones by a single basal thread. It is highly tolerant of low oxygen levels and survives well in polluted environments (information from NIMPIS website: [cited 11-Sept-08]) or areas of disturbance and high organic loading (*Varicorbula* NCP 2008).

Impacts

Varicorbula can obtain extremely high densities with soft sediments, for example 1200 individuals/m^2 have been measured in Port Phillip Bay (*Varicorbula* NCP 2008). This species is therefore considered a potential threat to settlement success of native bivalves and other bottom-dwelling species, and may significantly alter the ecology of benthic habitats. It may also have the potential to alter benthic ecology in those areas where it occurs in high abundance by consume much of the primary productivity that may have other wise been available to native benthic species. It is noted as potentially impacting upon growth rates of scallops and the bivalves *Katelysia* sp. and *Venerupis* sp. (*Varicorbula* NCP 2008).

Derwent Estuary *Varicorbula* distribution and management considerations

In Tasmania, *Varicorbula* is thought to be associated with sediments that are enriched in organic material, such as seafloor areas beneath salmon farms (Edgar *et al.* unpublished, in *Varicorbula* NCP (2008)). Highest organic loadings in the Derwent Estuary occur in the upper estuary (**Figure 5**); however *Varicorbula* is not as abundant here as in the middle and lower estuary.

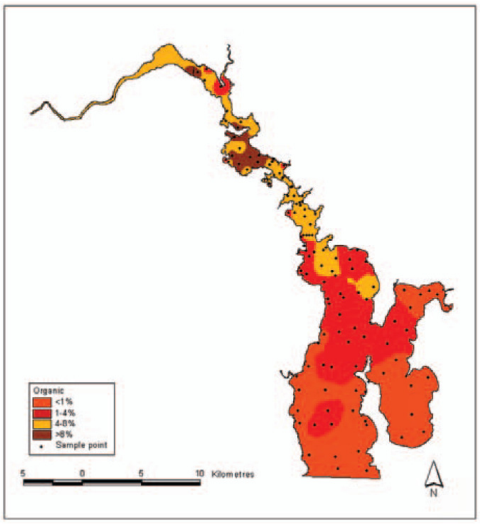


Figure 5. Total organic carbon (TOC) content in Derwent Estuary sediments (State of the Derwent Report 2003). High TOC values in the upper estuary could be preferred substrates for *Varicorbula.*

In the Derwent Estuary *Varicorbula* is.found to thrive in areas with organic carbon levels between 4% and 8% primarily in the middle and outer estuary with an average abundance of 96 individuals/m^2 (McLeod and Heliodoniotis 2005) (**Figure 6**).

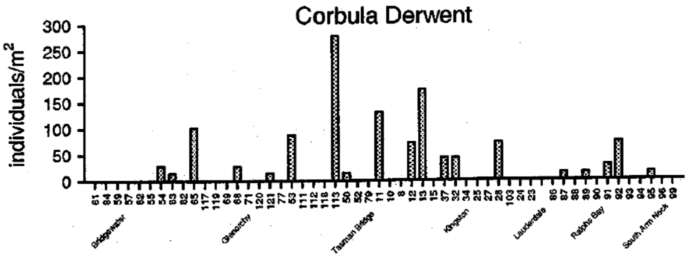


Figure 6. Distribution and abundance of *Theora lubrica* in the Derwent Estuary, Nov. 2004 (MacLeod and Helidoniotis 2005).

Although *Varicorbula* is supposedly has a wide tolerance to a broad range of environmental conditions the relative low numbers in the upper estuary may question its ability to survive environmental stresses inherent here, such as low salinity caused due to flooding events. *Varicorbula* has a minimum salinity tolerance of 26 ppt (information from NIMPIS website: http://www.marine.csiro.au/crimp//nimpis/ [cited 11-Sept-08]). The abundance of *Varicorbula* can experience 'boom and bust' cycles where massive recruitment events are often followed by recovery of pre-disturbance invertebrate populations and eventual decline of *Varicorbula* abundance (Edgar *et al.* unpublished, in *Varicorbula* NCP (2008)).

Impact management objectives

Understanding the economic and environmental impact of *Varicorbula* is vital because it plays a pivotal role in determining whether or not control actions should be pursued. *Varicorbula* establishes in high densities in response to habitat degradation – inparticular due to organic loading. It is also likely that *Varicorbula* is being prevented from establishing in the upper Derwent Estuary due to freshwater flushing events that lower salinity below the tolerance level of this species. A potential Derwent Estuary *Varicorbula* management objective could be:

1. *Protect and improve natural habitat to reduce & prevent Varicorbula establishment.*

Impact management options

Impact management options in the *Varicorbula* NCP (2008) are defined under two broad categories: *1) Direct targeting of Varicorbula,* and *2) Habitat management* (discussed below). It is possible that habitat management may assist in meeting the above proposed management objective.

<u>1) Direct targeting of *Varicorbula*</u>

Physical removal

Varicorbula can occur in water depths 6 to 146m (information from NIMPIS website: http://www.marine.csiro.au/crimp//nimpis/ [cited 11-Sept-08]), occurrences >20m depth eliminate diver removal as a possible control option. Dredging has been proposed as one control approach, but in the Derwent this is not acceptable due to disturbance of heavy metal contaminated sediments. The effectiveness of this approach has also been questions, due to *Varicorbula*'s ability to quickly recolonise areas disturbed by dredging *(Varicorbula* NCP 2008).

Biological control

It may be possible to keep *Varicorbula* populations low through enhancing the presence of native predators within the Derwent.

2) Habitat management

Habitat management is currently considered the most feasible impact management strategy for *Varicorbula (Varicorbula* NCP 2008). There appears to be a link to high *Varicorbula* population density where sediment organic content is high. Management of anthropogenic sources of nutrients and organic enrichment into the coastal zone is a potential strategy that may indirectly control *Varicorbula* population density *(Varicorbula* NCP 2008). This may include management of point-source (e.g. industrial waste, sewage) and diffuse pollution sources associated with land-based activities (e.g. agriculture, urbanisation) around the Derwent. Improvement in habitat quality typically leads to recovery of stable benthic communities and consequently a gradual replacement of dense *Varicorbula* populations with native predators and competitors (*Varicorbula* NCP 2008).

General considerations

Norske Skog Boyer paper mill was the main contributor of point source organic loading to the estuary, but with a change in their treatment process in late 2007 this has been dramatically decreased. Although sediment organic levels remain high in the upper estuary, *Varicorbula* may be prevented from establishing due to low salinity events (minimum salinity tolerance of 26 ppt), therefore a flow regime that enables periodic freshwater flushing of the upper estuary may help in preventing high densities of *Varicorbula* establishing here. As far as being able to reduce occurrences of *Varicorbula* in the middle and outer estuary it has been recognised that any broader strategy that aims to improve ecosystem health is likely to assist (*Varicorbula* NCP 2008). A management option may be to reduce sediment organic content in the middle and outer estuary by decreasing nutrient and organic loadings by expanding the reuse of treated waste water effluent for irrigation and other uses.

European green crab (*Carcinus maenas*)

The European green crab (*Carcinus maenas*) is thought to have possibly reached Tasmania, from mainland Australia through natural long distance larval dispersal (Aquenal 2002). *Carcinus maenas* is a medium-sized crab that attains a width across the carapace of up to 80mm, but more typically 65mm. It is an extremely tolerant and hardy species, showing few limitations of the type of habitat it prefers. It is found in both the intertidal and shallow subtidal zones of less energetic bays and estuaries rather than exposed, rocky or sandy open coasts. In Tasmania, *C. maenas* has been found in a wide range of habitat types within estuaries and bays, occupying both heavily sea-grassed areas through to non-vegetated areas with a clean sandy bottom (information from NIMPIS website: http://www.marine.csiro.au/crimp//nimpis/ [cited 11-Sept-08]). The most recent *C. maenas* management recommendations are documented in the revised "*Carcinus* National Control Plan (NCP) 2008" created by Aquenal Pty Ltd in April 2008 for DEWHA.

Impacts
Its impact on native species in Australia is difficult to ascertain due to its long history as part of the Australian intertidal and shallow water fauna, and lack of adequate baseline studies in these habitats prior to its establishment. However, on the basis of its invasive history in other parts of the world and given that the crab is a voracious predator with a broad diet, it is likely to have had a substantial impact. In Tasmania, *C. maenas* has been present for about 20 years and is a major cause of mortality in native crab and mollusc populations (information from Hayes *et al.* (2005) and NIMPIS website: http://www.marine.csiro.au/crimp//nimpis/ [cited 11-Sept-08]). *Carcinus* appears to have a much greater environmental impact in Tasmania compared to the impact that may have occurred in mainland Australia, because some native competitor species are not present in Tasmania (*Carcinus* NCP 2008).

Derwent Estuary *C. maenas* distribution and management considerations
Carcinus maenas is found in sheltered intertidal and shallow subtidal depths, preferring depths around 3m in Tasmania (*Carcinus* NCP 2008). *Carcinus maenas* feeds on many species of sessile and mobile epifauna and readily detect and capture shallow infauna. In Tasmania, *C. maenas* is a significant predator of the venerid clam *Katelysia scalarina* (Walton *et al.* 2002). There is clear evidence that where *Carcinus* is present, *Katelysia* populations decline due to depressed survival to adulthood (Walton *et al.* 2002). Current evidence suggests that impacts are restricted to lower trophic levels, since there have been no demonstrated impacts on higher trophic levels (notably shorebirds Grosholz *et al.* 2000, in *Carcinus* NCP (2008)). This impact is exacerbated by similar pressure on bivalve population by *Asterias* (Ross *et al.* 2004). However, the Aquenal (2002) survey did not detect any *Carcinus maenas* in the Derwent Estuary, indicating that it occurs at least periodically in some sections of the estuary. There is no clear evidence at this stage to suggest that *C. maenas* has impacted on the Derwent Estuary environment, however this species is considered a future threat due to the potential for rapid expansion of both its geographic range and population numbers (Aquenal 2002). *Carcinus maenas* will most likely change the ecology of intertidal and shallow subtidal habitats in the Derwent Estuary through predation on native organisms

Impact management objectives & options
Impact management options in the *Carcinus* NCP(2008) are defined under two broad categories: *1) Direct targeting of Carcinus,* and *2) Habitat management,* (discussed below). A critical question when deciding whether or not a management response is required is "Do benefits of impact management exceed costs"? Understanding the impacts of *Carcinus* is potentially complex and may differ depending on the region concerned. Some comments on the most acceptable, and currently feasible management options that could be used in the Derwent are as follows:

1) Direct targeting of *Carcinus*

Physical removal

Of the currently available impact management options, trapping is considered the most acceptable method; however, the effectiveness of reducing *Carcinus* population size and impacts may be questionable (*Carcinus* NCP 2008). There is a lack of empirical data to indicate the effectiveness of trapping, but trapping is still considered a management option in smaller-restricted embayments, where localized population declines may be achieved (*Carcinus* NCP 2008). If trapping is undertaken in Tasmania, it has been noted that higher catch rates are achievable during warmer periods in summer (Martin & Proctor 2000, in *Carcinus* NCP (2008)).

2) Habitat management

Protect and enhance native predators or competitors

On mainland Australia the blue swimmer crab (*Portunus pelagicus*) is considered to out-compete *Carcinus* (*Carcinus* NCP 2008). Research may be required to identify what native competitors and predators occur in Tasmania and how these can be protected or enhance as a mean of controlling *Carcinus* population numbers.

General considerations

There is a need for a systematic Derwent Estuary survey of *Carcinus* distribution and abundance, and identification of the environmental, economical and social values at threat. This information will aid in the identification of appropriate and effective management objectives.

Impact management strategies should focus on reducing *Carcinus* abundance and impact in high value areas: such as the Tinderbox Marine Reserves (if present) and, regions where threatened species or communities occur in the Derwent that will be impact by *Carcinus* presence. Risks posed by *Carcinus* to Derwent Estuary threatened species, such as Spotted Handfish, need to be assessed. Long-term reduction in pest abundance should be considered as a realistic management objective in areas that are not necessarily considered ‘high value’, but where the chances of impact reduction are high. For example, in small bays and inlets, long-term reduction (or even eradication) of *Carcinus* populations may be achievable with relatively little effort (*Carcinus* NCP 2008). Community (volunteer) based trapping may be an acceptable option, in some areas of the Derwent Estuary. This species may also be found appropriate for human consumption (as in Europe), provided that this does not pose any human health risks and that trapping does not lead to translocation or the removal of non-target native species (which may be assisting in the control of introduced species).

Carcinus control may be warranted in those areas of the Derwent that may pose a high translocation risk to other areas free of this species. The invasion dynamics of *Carcinus* may influence control strategies, as this species seems to have sporadic widespread recruitment separated by intervals of several years of little migration of established populations (Thresher *et al.* 2003). It may be possible to fish down populations of *Carcinus* in those areas posing high risk as a translocation source, or are in areas with high environmental values that are being impacted by *Carcinus* presence.

Rice grass (*Spartina angelica*)

Rice grass *Spartina angelica* is a vigorous salt marsh plant that typically inhabits the upper intertidal zone of temperate estuaries. Rice grass was introduced to the Tamar Estuary in 1947 with the goal of stabilising mudflats, reclaiming intertidal lands and improving navigation. The plant spread rapidly throughout the estuary, and subsequently to other parts of the state including the Derwent Estuary.

Impacts

Its dense growth and root network act as a trap for sediment, significantly altering the natural rate, magnitude and location of sediment deposition and erosion. These processes eventually elevate shorelines and river banks, creating rice grass terraces and marsh islands, which have significant impacts on estuarine hydrodynamics, ecology and amenities. Impacts on biodiversity and integrity of native wetland communities, migratory birds and fisheries are of particular concern. Furthermore, rice grass adversely affects recreational amenities (Hedge 1997).

Derwent Estuary *Spartina* distribution and management considerations

In 1995, approximately 2 hectares of *Spartina* were documented in the middle and upper reaches of the Derwent. Rice grass has the potential to invade 180 hectares of intertidal habitat in the Derwent Estuary region. Rice grass currently inhabits <0.001% of its potential range in this region. Infestations have the potential to dramatically alter the ecological and natural heritage of the estuary. Invasion alters the distribution and habits of a range of resident flora and fauna, including shore birds, fish, invertebrates, seagrasses and saltmarsh. Infestations progressively invade the immediate and surrounding area of intertidal zones altering estuarine sediment dynamics, effecting navigation and tourism. Rice grass may inhibit coastal access and use, and detrimentally effect recreational fishing and boating.

Regular *Spartina* surveying and treatment (spraying with Fusilade Forte) has been occurring over the last few years, and has reduced the known area to ~4m^2 (January 2008) at several sites (**Figure 6**). *Spartina angelica* seed can remain viable for up to six years after flowering, and as a consequence a long term monitoring program would be required until any occurrences can be declared 'successfully eradicated'.

Figure 6. January 2008 *Spartina* distribution around the Derwent Estuary foreshore (source DPIW).

The first survey of habitats up-river of the Bridgewater causeway was carried out by the Derwent Estuary Program in 2008 and no *Spartina* was observed.

Impact management objective
Eradication of *Spartina* from the Derwent Estuary is the management objective. The most recent management plan "Rice Grass Area-Based Management Plan Derwent Estuary (2006-2008)" undertaken by DPIW, in collaboration with the DEP, and was funded by the Natural Heritage Trust. This management plan has working associations with other management documents;

- Derwent Estuary Environmental Management Plan (2001)
- Strategy for the Management of Rice Grass (*Spartina anglica*) in Tasmania. Second edition (2002);
- State Coastal Policy (1996);
- Weedplan (Tasmanian Weed Management Strategy) (1996).

Impact management options

<u>1) Direct targeting of *Spartina*</u>

Chemical control

Areas in the Derwent Estuary are being surveyed once, or twice a year, for *Spartina* and known occurrence are being treated with Fusilade Forte.

General considerations
Whilst effective control has occurred, eradication has not been achieved and funding for the current management plan will finish at the end of 2008. An alternative funding model for the control program is required, as eradication is achievable in the short term if survey and treatment continues. A potential *Spartina* occurrence spotted at a distance by *NorthBarker ecosystem services* botanists in mid-2008 in the upper estuary above the Bridgewater causeway warrants investigation. As *Spartina* seed can remain viable for six years within sediments, it will be necessary to continue longer-term monitoring for the presence of this species in the Derwent Estuary before eradication can be declared.

Toxic algal blooms (*Gymnodinium catenatum*)

The presence of the toxic alga (dinoflagellate) *Gymnodinium catenatum* in Australian waters was confirmed in 1985, when it was positively identified in the Derwent Estuary. Vegetative cells can be distributed throughout the whole water column with a resting stage (cysts) being found in sediments. There is irrefutable evidence that the cysts were not present in Tasmanian sediments before 1972-73, more accurately indicating the timing of its first introduction (McMinn *et al.,* 1997).

Impacts
Numerous animals feed on dinoflagellates, including filter-feeding species (e.g. bivalves) and small animals which directly consume the dinoflagellate microalgae (e.g. zooplankton). Potent dinoflagellate neurotoxins accumulate in the bodies of these animals and can be passed along the food chain. Ingestion of affected shellfish by humans, and other organism, can cause Paralytic Shellfish Poisoning (PSP). In extreme cases, PSP causes muscular paralysis, respiratory difficulties, and can lead to death (Ochoa *et al*., 1998).

Derwent Estuary *G. catenatum* distribution and management considerations
Subsequent to *G. catenatum* introduction into Tasmania there is evidence that distinct strains of *G. catenatum* may be evolving in response to different conditions within different estuaries (e.g., the Huon and the Derwent estuaries) (Bolch *et al.* 1999). The development of distinct strains also suggests that there has been little genetic exchange and sexual interbreeding between estuaries (Bolch *et al.* 1999). Bloom formation in the Huon Estuary appears to be linked to the incidence of freshwater input after rainfall (contributing organic and inorganic growth factors) and is associated with extended periods of low wind-stress (Hallegraeff *et al*. 1995). Selenium is considered important for *G. catenatum* growth, and its introduction into coastal systems comes from in land runoff and in the Huon estuary selenium interacts with dissolved organic substances (CDOM) and alters the supply of nutrients available for algal growth (Doblin *et al.* 1999). In the Derwent Estuary *G. catenatum* appears to have been adapting to low selenium conditions, in that it has changed it's response to selenium deficiency, with the Derwent 1987 strain exhibiting a reduction in biomass yield (when conditions are selenium deficient), whilst the Derwent 1993 strain did not (Doblin *et al.* 2000).

Corresponding changes in abundance in *G. catenatum* in the Derwent Estuary wild populations are harder to assess, as there is no routine algal monitoring undertaken in the Derwent Estuary. This is largely the consequence of no monitoring of shellfish in the Derwent for PSP toxins due to heavy metal contamination prohibiting shellfish aquaculture and the public advisories against the harvesting of Derwent shellfish for consumption. The Derwent Estuary Program undertake monthly chl-a measurements (composite water surface profile to 5.4 or 9.5 m) and fluorescence measurements through the water column in the outer estuary, but no algal species identifications are performed. Derwent Estuary algal research has typically occurred through University, CSIRO and industry based projects or assessments.

Impact management objectives & options
Blooms of toxic dinoflagellates are usually short lived (several weeks), but occasionally have lasted for three months. Reported blooms for *G. catenatum* have occurred from October to May, but there is evidence (from 2008) that the growing season may be extending through the winter months (G. Hallegraeff, pers. comm.. 29-Oct-2008). Their cysts can remain dormant in the sediment for several years, germinating and causing blooms only when conditions become favorable. Eradication is not possible, and options for control are limited to preventing the further spread of the species and minimising activities that might promote bloom formation.

General considerations
Information on human health risks from consumption on Derwent shellfish (DEP Brochure released July 2007- downloadable from website: http://www.derwentestuary.org.au/index.php?id=9 [cited 19

Sept 2008]), could in future include information on PSP as well as the current advisory on heavy metals. The impact of native fauna consumption of PSP contaminated shellfish or direct contact with *G. catenatum* blooms may warrant further research in order to fully assess environmental impacts. There is considerable evidence that *G. catenatum* can be readily transported in ballast tanks. Preventing the uptake of contaminated water and sediment during re-ballasting operations is therefore a crucial component of reducing risk of translocation to new areas.

Routine phytoplankton species abundance assessments are not undertaken in the Derwent Estuary. The conditions required for *G. catenatum*, may be similar to those in the Huon Estuary, and routine algal bloom monitoring off Port Esperance can be used as an early warning for blooms in the nearby Derwent Estuary. However, given that different strains occur in the Huon and Derwent Estuaries, their physiology and bloom response may slightly differ. Blooms in the Huon have also been linked to freshwater inputs from the Huon River, which is not synchronous with more flow regulated Derwent River. The frequency of Derwent *G. catenatum* blooms is unknown. If *G. catenatum* blooms are having deleterious impacts on native species in the Derwent Estuary, it may be appropriate to monitor and manage the estuary in a manner that decreases the frequency and size of such events. For example, minimising seafloor disturbance (from dredging or other activities) that is likely to re-suspend and activate *G. catenatum* cysts present in the sediment.

Pacific Oyster (*Crassostrea gigas*)

The Pacific oyster *Crassostrea gigas* was deliberately introduced to southern Tasmania in 1947 to establish the oyster aquaculture industry, following the collapse of the wild native oyster (*Ostrea angasi*) fishery (Mitchell *et al.* 2000). Initial introduction to Tasmania was seeded in Pittwater, east of the Derwent Estuary; however, this population did not grow successfully. Later introductions were made in North West Bay, northern D'Entrecasteaux Channel in 1963 (Mitchell *et al.* 2000), and may have initiated spread into the Derwent Estuary. The Pacific oyster, as an intentional commercial introduction, has greatly added to the economic base of southern Australia. Despite the benefits, the adverse effects of the oysters include: loss of coastal aesthetic and amenity value due to large and often dense intertidal settlements, organic enrichment of sediments (due to oyster faeces), risk of injury to coastal marine users, and damage to property (due to sharp edges of oysters). Pacific oysters may, in some regions, compete for space with native oysters and carry a parasitic copepod (*Mytilocola orientalis*) which can be passed on to certain other bivalves e.g. mussels. A survey was undertaken during spring-summer 1999/2000 around mainland Tasmania (included the Derwent Estuary) to record baseline data on the distribution and abundance of feral Pacific oysters (*Crassostrea gigas*) and to describe the environmental conditions that they inhabit. A photographic record was taken of each site and estimates of oyster densities and size range were recorded at sites where oysters were found (Mitchell *et al.* 2000).

Impacts

Introduction of *Crassostrea gigas* to Tasmania has enabled the establishment of a lucrative oyster aquaculture fishery. However, there has also been public concern about the spread of feral Pacific oysters from existing marine farms, and the risk of spread from proposed new farms. The concerns raised relate to aesthetics, the hazards of feral oysters (cut feet, damage to boats, etc) resulting in loss of amenity of the coastline, and also the likelihood of impact on local environments (Mitchell *et al.* 2000).

Feral Pacific oyster settlement is generally confined to the intertidal regions of shorelines, and then depending upon factors such as: appropriate substrate, sheltered conditions, freshwater influences, water temperatures, reduced likelihood of predation and dispersal (hydrographic regimes) (Mitchell *et al.* 2000). Once established in a location, oysters are able to further expand their range through tidal and oceanic dispersion of larvae. Pacific oysters have a lengthy planktonic larval stage of 3-4 weeks. Quayle & Newkirk (1989) recorded larvae moving at least 80 kilometres away from the spawning site.

Impacts on native rock oyster species has been generally noted in literature; however, in Tasmania the native oyster species is *Ostrea angasi*, which typically occupies soft bottom substrates in subtidal environments 1-30 m deep (Edgar 2000). This is not the preferred habitat of *Crassostrea,* typically found attached to hard substrates but occasionally reef forming on soft sediments if larvae attach to pebbles or other hard substrates (Mitchell *et al.* 2000). In Tasmania the native *Ostrea angasi* population had been reduced from much of its pre-European habitat due to fishing pressure. Large *Ostrea angasi* populations had once occurred throughout many bays within the Derwent Estuary prior to European fishing pressure (Harrison 1994) and possibly introduced disease (e.g. *Bonamia*) (Aquenal 2002). However, observation inference had linked *Ostrea angasi* decline in West Arm on the Tamar River (between 1955 and 1959), with *Crassostrea* introduction and establishment (Mitchell *et al.* 2000), but the correlation was not proven. It is possible that *Crassostrea* may hinder recovery of *O. angasi* populations (Aquenal 2002).

Derwent Estuary *Crassostrea* distribution and management considerations

In Tasmania, *Crassostrea* occur in a wide range of habitats and attached to a broad range of substrate types (Mitchell *et al.* 2000). The statewide survey in 1999/2000 indicated the predominant substrate favoured by Pacific Oysters (in moderate to high densities) was sedimentary rock, with attachment of oysters over a wide size range of substrate types from pebbles to rock platforms. The main factors which restricted settlement, regardless of suitable substrate, were high exposure and fetch. It appears that in high wave energy areas successful larval settlement is prevented or settled oysters become dislodged (Mitchell *et al.* 2000). Pacific Oyster populations within the Derwent Estuary (**Figure 7**) may have stemmed from North-West Bay (near Margate) with larvae transported via tidal currents which predominantly move along the western shoreline of the estuary (Mitchell *et al.* 2000).

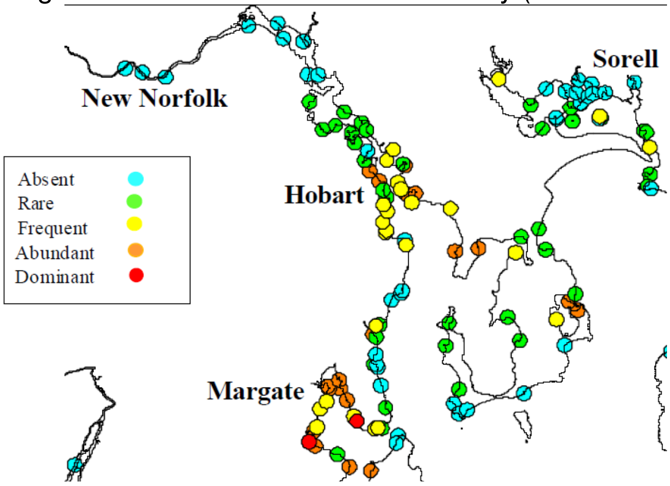


Figure 7. Pacific Oyster (*Crassostrea gigas*) distribution around the Derwent Estuary foreshore in spring-summer 1999/2000 (Mitchell *et al.* 2000).

Public amenity and aesthetic landscape values are impacted by feral oysters in the Derwent Estuary. The most popular Derwent Estuary recreational swimming locations are typically outer estuary beaches, and up river locations such as New Norfolk, where oysters are absent. However, boat ramps and jetties, rocky shore diving and snorkelling sites, and rocky shore dog walking areas are some examples of Derwent Estuary amenities impacted by *Crassostrea* growth on hard substrates and posing risk of injury.

The Derwent Estuary had no native rock oyster species; however other native bivalves (e.g. Blue Mussels, *Mytilus edulis*) occupy a similar niche that could be colonised by introduced *Crassostrea.* Pacific oysters can co-exist with native mussels (Reise 1998); however, there is potential for change in the shellfish species balance, which also has the potential to impact on other species through this habitat modification (from website: http://www.fish.wa.gov.au/docs/pub/IMPMarine/IMPMarinePage08a.php?0506 [cited 18 Sept 2008]). Oysters are filter feeders, consuming large quantities of microscopic phytoplankton, detritus and particulate matter, which are found throughout the marine environment and thus also create competition with native filter feeding organisms. One of the most influential factors affecting oyster growth, and thus food consumption, is water temperature. In Tasmania most rapid growth occurs in the late summer months and generally ceases during winter (Mitchell *et al.* 2000).

Impact management objectives

Understanding the economic and environmental impact of feral *Crassostrea* is vital because it plays a pivotal role in determining whether or not control actions should be pursued. If the economic and environmental impacts identified warrant a management response, it is imperative that impact management objectives are defined. Potential Derwent Estuary objectives may focus on:

1. *Reduce Crassostrea from areas of high public foreshore amenity*
2. *Protect high value natural habitat from Crassostrea related impacts*

Crassostrea has become established in the middle and outer Derwent Estuary, and as such will be very hard to eradicate (Mitchell *et al.* 2000). Even if all *Crassostrea* were eradicated from the Derwent

Estuary, management would remain ongoing as feral *Crassostrea* populations within D'Encastreaux channel remain a source for reintroduction. Individual *Crassostrea* can survive for a number of years during which time they produce and expel large numbers of potential offspring, the larvae can travel up to 80 km before settling (Quayle & Newkirk 1989). Nevertheless, there are large areas in the Derwent Estuary with suitable *Crassostrea* habitat but have low infestation levels, such as Ralphs Bay and South Arm (based on 1999/2000 survey by Mitchell *et al.* (2000)). Targeting control efforts in the areas with low infestation levels may increase the potential for successful localised control.

Impact management options
Several *Crassostrea* control options are reviewed in Mitchell *et al.* (2000). Any management option focusing upon the Derwent Estuary, or high value areas within the Derwent, would also need to consider perpetual ongoing management of re-infestations.

<u>1) Direct targeting of *Crassostrea*</u>

Physical removal

Oyster smashing sessions by community groups has been undertaken around Tasmanian to reduce oyster infestations in areas of high community value. This control activity has been occurring in the Derwent Estuary, Clarence Municipality

> "The Tranmere–Clarence Plains Land and Coastcare group was the first in the country to tackle the problem of feral Pacific oysters, which have been declared a pest of national significance. ……The group succeeded in smashing approximately 3000 feral Pacific oysters on CUAD [*Clean up Australia Day*] and will continue this work into the future". (page 15 *Tasmanian Conservationist* (May 2007) Issue 311: downloadable from http://www.tct.org.au/neAp07.pdf. [cited 18 Sept 2008)).

The two Drought Point oyster occurrences in the above oyster distribution map, have been the focus of this eradication effort. Several follow-up trips have occurred since the initial control effort (Wendy Andrews (secretary Tranmere–Clarence Plains Land and Coastcare) pers. comm. 19 Sept 2008). Whilst the effectiveness of smashing *Crassostrea* within intertidal habitats, and leaving *in situ*, has not been formally assessed, this is comparable to 'oyster fishing pressure' which has been described elsewhere as helping to locally controlled oyster populations.

Genetic Control

Genetic modification, to create triploid oysters (which have three times the haploid number of chromosomes), lowers oyster fecundity by reducing gamete development (Mitchell *et al.* 2000). The development of viable female tetraploid oysters that would spawn diploid eggs, which when fertilised with normal sperm from feral populations, would yield 100% triploid progeny, effectively producing a generation of inferior individuals (Eudeline *et. al.* 2000). The tetraploid oysters could act as a broodstock that can modify the genetic make-up of the feral population; however, Mitchell *et al.* (2000) recommend that the broodstock would need to be monitored to reduce problems that may arise if there is inbreeding. Mitchell *et al*. (2000) also describe genetic modifications that were being developed at the CSIRO Marine Laboratories in Hobart to be applied to Pacific Oysters. This had involved the genetic modification of hatchery spat to produce reversibly sterile individuals. Spawning would be impossible unless individuals were treated with chemical cues. If successful, these oysters could also interbreed with existing feral populations to initially reduce further colonisation around the coast, and over time, lower the number of feral oyster populations around the state. The feasibility of this approach warrants investigation.

General considerations

Derwent Estuary control of *Crassostrea* has been community driven, through the efforts of groups such as the Tranmere–Clarence Plains Land and Coastcare group. This and other similar groups could be encouraged to target control in those areas with high natural, social and aesthetic value. It may be possible to compare areas of high public amenity and high environmental values at risk from Pacific Oysters, with 1999/2000 oyster distribution map to gauge priority areas for potential management. The importance of community involvement in *Crassostrea* monitoring was also noted by the first statewide survey organisers, Mitchell *et al.* (2002). This statewide survey included development of community based monitoring fieldsheets and a training session for Fishcare volunteers. A similar program could be reinvigorated for the Derwent Estuary to assist in monitoring changing *Crassostrea* distributions and density and the effectiveness of control.

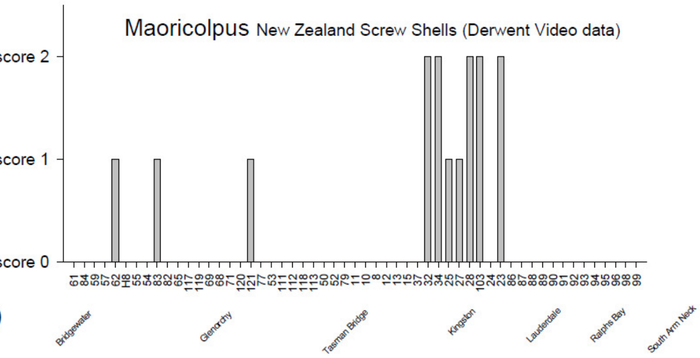
New Zealand screw shell *(Maoricolpus roseus)*

The New Zealand screw shell *(Maoricolpus roseus)* was introduced to southeastern Tasmanian in the 1920's and has since spread out to the 80 m bathymetric contour and advanced up the eastern seaboard to New South Wales (Bax *et al.* 2003). *Maoricolpus* is a filter feeder and is found on all substrata from soft sediments to exposed rocky habitats, living in crevices on rock walls, and sheltered pockets on more exposed reefs from low-water to approximately 200 metres depth (reviewed by Scott (1997)). Due to the wide range of habitats occupied, the potential exists for *Maoricolpus* to have greater ecological and environmental impacts than many other introduced pest species that are restricted to specific inshore environments. Until recently very little was know about the reproductive biology of this species. The larva are released from egg capsules and are planktonic and feed on microalgae, enabling *Maoricolpus* to be readily dispersed by currents or in ship ballast (Probst and Crawford 2008).

Impacts
At a national level, *Maoricolpus* is impacting an area of seafloor equivalent to the area of Tasmania, and may be the most significant environmentally impacting marine pest in the country (Patil *et al.* 2004). Whilst *Maoricolpus* can occupy a range of substrates, it has a preference for coarse or firmer sediments, in areas of moderate to strong water currents that are favourable to this filter feeder (information from NIMPIS website; http://www.marine.csiro.au/crimp//nimpis/ [cited 15-Sept-2008]).

Maoricolpus can form very dense populations, altering sediment structure through the consolidation of mobile sediments, and the creation of shell deposits many layers deep (Patil *et al.* 2004). *Maoricolpus* directly competes with native benthic filter feeders for food and habitat, and is thought to have caused declines in native scallop and native screw shells (turritellids such as *Gazameda gunnii*) (Bax *et al.* 2003; Patil *et al.* 2004). The empty *Maoricolpus* shells also provide habitat for hermit crabs, which would not have been available, or abundant, in large areas of sandy substrates, inturn leading to increased predation on native scallops and native screw shells (Patil *et al.* 2004). It is unclear if the primary presence of dense populations of *Maoricolpus,* competing with the native species for food and habitat is a greater impact than the secondary impact arising from the increased presence of hermit crabs predation on other native species. The empty *Maoricolpus* shells can also provide holdfasts for other introduced marine pests (N. Bax, pers comm. in Patil *et al.* (2004)).

Derwent Estuary *Maoricolpus* distribution and management considerations
In Tasmania, *Maoricolpus roseus* is so abundant in some areas that the benthic habitat has been altered from one of fine sand or mud to one with a dense cover of live and dead shells and faecal pellets (C. MacLeod, in Bax *et al.* (2003)). Surveys have been conducted at the entrance of the Derwent Estuary, at Tinderbox, where *Maoricolpus* populations reach up to 1500 individuals/m^2 (Probst unpublished data, in Probst and Crawford (2008)). The native screw shell, *Gazameda gunnii*, has declined such that it is now a threatened species in Tasmania, and vulnerable at a national level, due to the presence of *Maoricolpus* (Patil *et al.* 2004). Many *Maoricolpus* shells can be found washed up on beaches in the outer estuary at Kingston and Blackmans Bay (Whitehead, pers. obs.). Underwater deployed video assessment appears to be more useful than sediment grab sampling for evaluating the distribution of *Maoricolpus* (MacLeod and Helidoniotis 2005). The video gave a better approximation of quantities for this large gastropod (but live and dead individuals could not be distinguished from one another), whilst in areas where there were large beds of *Maoricolpus* the shells often jammed in the sediment grab jaws (MacLeod and Helidoniotis 2005). Video data from the Derwent Estuary indicated that *Maoricolpus* were most common in the outer estuary in the area between Kingston and the northern tip of South Arm, where they occur in a broad band across the mid-channel of the estuary, see **Figure 8** (MacLeod and Helidoniotis 2005).



a)

Figure 8. Distribution and abundance of *Maoricolpus* in the Derwent Estuary, Nov. 2004, from video survey. Score 0 = not present, 1=few (1-2 individuals), 3=many (>2 individuals) (MacLeod and Helidoniotis 2005).

Despite its wide distribution and dense populations, detailed aspects of the biology of *M. roseus* and its ecological impacts on the Tasmanian marine environment have not been studied (Bax *et al.* 2003). Large populations of filter feeders can have dramatic influences on nutrient cycling and algal biomass and can even reduce algal abundance (e.g. as in SanFransico Bay (Carlton *et al.* 1990)). It is unclear if dense populations of *Maoricolpus* are having this effect at the entrance of the Derwent Estuary. Water samples from the Derwent Estuary, indicate planktonic *Maoricolpus* larvae are present at marinas and wharf areas (Gunasekera *et al.* 2005), thus posing translocation risk to areas interstate and on the Tasmanian west coast where *Maoricolpus* is not yet present.

General considerations

No impact management objectives or options are currently developed other than reducing risk of translocation to other areas. There may be value in mapping the full extent, and improving monitoring, of *Maoricolpus* in the Derwent Estuary using an autonomous underwater vehicle (currently CSIRO may have this capacity).

New Zealand seastar *(Patiriella regularis)*

Patiriella regularis is found in many types of habitats from the low tide mark to 100m, such as fine sand substrata, reef and bedrock areas. During the Aquenal (2002) field survey this species was widespread in the Derwent Estuary and was present at nearly all sites surveyed between Nyrstar and Royal Yacht Club of Tasmania. Based on numbers of *P. regularis* caught in traps, the highest densities of this seastar were recorded at the Selfs Point Jetty, the Macquarie and Princes Wharves, the CSIRO Marine Wharf and Victoria Dock. The highest number caught per trap was 76 at the Selfs Point Jetty, however numbers per trap exceeded 50 at a range of other sites (Aquenal 2002). The widespread and abundant nature of *P. regularis* during the survey suggests that it has significantly impacted on natural communities. It is noteworthy that the highest *P. regularis* abundances were found within the habitat range previously occupied by the Derwent endemic seastar *Marginaster littoralis.* In New Zealand, *P. regularis* is consumed by fish found on rocky reefs. There have been no recorded predators of *P. regularis* in Australian waters. It is possible that *P. regularis* competes with the native species of *Patiriella* such as the Tasmanian threatened *P. vivipara* for food and other resources, and the possibly extinct *Marginaster littoralis* (information from website: http://www.marine.csiro.au/crimp//nimpis/ [cited 19 Sept 2008]).

New Zealand half crab (*Petrolisthes elongates*)

Petrolisthes elongatus has been in the Derwent Estuary for over a century, and now at some locations it obtains the highest densities (1621 individuals/0.1m^2 at the Royal Hobart Yacht Club) of any introduced species recorded in the estuary, and is likely to be having a large environmental impact (Aquenal 2002). Wharf pylons appear to be a favoured habitat with mean density of 329 individuals/0.1m^2 and it is also a dominant species amongst Derwent Estuary intertidal communities (Aquenal 2002). The lack of pre-introduction baseline biological data makes it difficult to fully gauge the impact of *P. elongatus* on community composition in the Derwent.

Other species

The following information concerning other introduced species has been obtain from the Aquenal summer of 1999/2000 Hobart port survey of the middle and northern-outer estuary areas (Aquenal 2002), and TAFI November 2004 ecological assessment of soft sediment biota in the middle (south of the Bridgewater causeway) and outer estuary regions (including Ralphs Bay) (MacLeod and Helidoniotis 2005). The following review includes comments on distribution and risks posed to natural habitats, but is not inclusive of all species observed.

Chilton glaucus (a New Zealand chilton) has been observed as abundant in the Derwent Estuary as early as 1923 (Aquenal 2002). Is now one of the most conspicuous and common chiton species in south-eastern Tasmania, and must be having some impact on the native species (Edgar 1997). The impacts of other introduced crab species, *Cancer novaezelandiae* and *Halicarcinus innominatus* are potential competitors with native crabs. The Aquenal (2002) survey of middle and northern section of the lower estuary suggested that *H. innominatus* is likely to have the greatest impact due to its wider distribution and higher abundance. Cryptogenic amphipod crustaceans, such as *Corophium* species, have been recorded in the Port of Hobart with densities reaching up to 31,500/m^2, for *Corophium acherusicum,* and 27,000/m^2, for *Corophium insidiosum*, although the former species was by far the most widespread of the two (Aquenal 2002). At high densities these species result in reduced sediment stability and may therefore exacerbate erosion (Gerdol and Hughes 1994, in Aquenal (2002)). Another cryptogenic amphipod species, *Caprella acanthogaster*, was also widespread in the

Derwent Estuary, and reached densities of up to approximately 2000 individuals per m^2 (Aquenal 2002).

There a number of introduced bivalves in the Derwent Estuary. Some Derwent Estuary distributional data include the species: *Varicorbula gibba* and *Crassostrea gigas* (already discussed), *Theora lubrica* and *Raeta pulchella* (Aquenal 2002; MacLeod and Helidoniotis 2005). *Theora lubrica*, originates from Japan and around the Korean peninsula, and reaches high densities in some areas of the outer estuary (~500 individuals/m^2, **Figure 9**) (MacLeod and Heliodoniotis 2005). *Theora lubrica* in Japanese waters is often the most abundant mollusc in shallow muddy bays and in some areas reaches densities in excess of 3000 individuals/m^2 (Tanaka and Kikuchi 1979), and thus has the potential to cause significant changes to the benthic communities in the Derwent Estuary (Aquenal 2002). *Theora lubrica* is more abundant in the outer Derwent Estuary, which may reflect its low tolerance to reduced salinity from freshwater inputs into the upper and middle estuary (MacLeod and Heliodoniotis 2005).

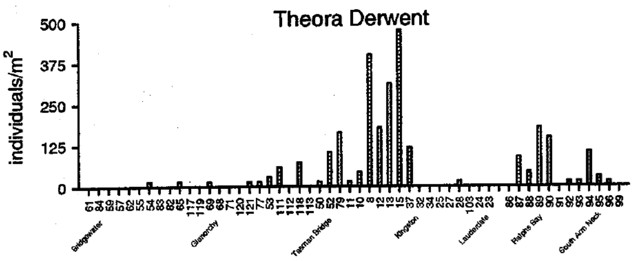


Figure 9. Distribution and abundance of *Theora lubrica* in the Derwent Estuary, Nov. 2004 (MacLeod and Helidoniotis 2005).

Raeta pulchella, a small bivalve native to South-East Asia (MacLeod and Helidoniotis 2005), was consistently recorded in low densities in the middle and outer Derwent Estuary areas surveyed during 1999/2000, which is thought to be due to its preference for brackish conditions (Aquenal 2000). A more widespread Derwent survey in 2004 indicated that this species is extremely patchy in distribution, although where it occurred numbers could exceed 200-300 individuals/m^2 (MacLeod and Helidoniotis 2005). There is little known about the biology or ecology of this species and so it is hard to predict what the potential local impact might be (MacLeod and Helidoniotis 2005).

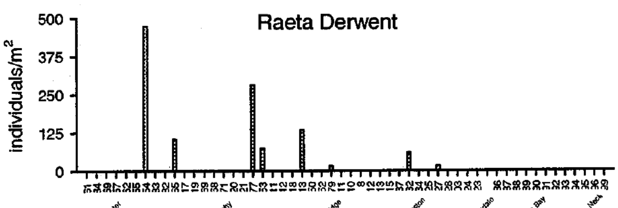


Figure 10. Distribution and abundance of *Raeta pulchella* in the Derwent Estuary, Nov. 2004 (MacLeod and Helidoniotis 2005).

The impact of introduced polychaete species in the Derwent Estuary has been little studied. The polycheate *Myxicola infundibulum*, is a cryptogenic species, which is widespread and forms dense colonies in the Derwent Estuary on artificial structures, however this species also occurs in natural environments and has the ability to displace native species (Aquenal 2002).

The introduced green alga *Codium fragile* ssp. *tomentosoides* has the potential to spread more widely through sheltered bays in the Derwent Estuary and exhibits nuisance growth on wharf pylons and other structures (Aquenal 2002). Introduced bryozoans also cause ecological impacts, such as the encrusting species *Membranipora membranacea* that can damage kelp beds by making kelp laminae brittle and inflexible, increasing the potential for surge damage, and encourages feeding by fish leading to further damage of the kelp (Aquenal 2002). The ascidians *Ascidiella aspersa* and *Ciona intestinalis* may divert a significant portion of particulate food away from native filter-feeding organisms (Currie *et al*. 1998, Cohen et al. 2001 in Aquenal 2002). Hydroids comprise another group of fouling species that have primarily been observed on jetties and other artificial structures in the Derwent, although it is possible that they can also be living on natural substrates. The most widespread hydroid species identified in the Aquenal (2002) survey were *Bougainvillia muscus*, *Clytia hemisphaerica* and *Plumularia setacea*. Other introduced hydroids with more restricted Derwent Estuary distributions include: *Cordylophora caspia*, *Ectopleura dumortieri*, *Phialella quadrata*, *Sarsia eximia* and *Turritopsis nutricula* (Aquenal 2002). *Cordylophora caspia* is currently restricted in its known Derwent Estuary distribution to Sullivan Cove (on artificial substrates at Macquarie wharf 5), but is know to have the potential to impact the benthic ecology of sheltered estuarine environments (Aquenal 2002). The ability of these introduced species to grow on a range of natural and artificial substrates may have implications for the ecology of the Derwent Estuary if they were to spread into seagrass and algal beds (Aquenal 2002).

Euchone limnicola is a small sabellid fanworm that lives in muddy sediments typically in the upper to upper-middle Derwent Estuary (**Figure 11**, MacLeod and Helidoniotis 2005).. In some locations it was extremely abundant (> 2,000 individuals/m^2), and appeared to prefer areas with a relatively high level of disturbance (MacLeod and Helidoniotis 2005).

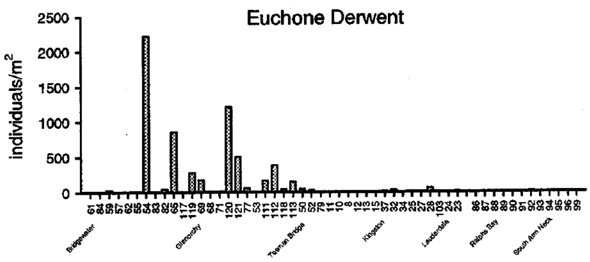


Figure 11. Distribution and abundance of *Euchone limnicola* in the Derwent Estuary, Nov. 2004 (MacLeod and Helidoniotis 2005).

Introduced salmonid species (e.g. *Salmo trutta*, *Oncorhynchus mykiss*) impact on native freshwater galaxiid fish species through predation and competition for habitat, but are not considered a major threat to marine communities (Aquenal 2002). *Salmo salar* (Atlantic salmon) escapees are not well adapted for feeding away from captivity and are often in poor condition (Edgar 1997) and thus are unlikely to have a significant impact on native species and habitats in the Derwent Estuary. Two fish species, *Grahamina gymnota* and *Grahamina varium* occur in the Derwent Estuary and may have been introduced from New Zealand (Aquenal 2002). *Grahamina varium* is very abundant on shallow reefs in temperate waters (Edgar 1997) and therefore if abundant on the Derwent it is likely to be modifying the ecology on shallow reefs habitats (Aquenal 2002).

SUMMARY

The Derwent Estuary contains in excess of 70 introduced marine and intertidal species. Many of these have serious environmental, economic and social impacts. The Derwent Estuary Program recognises that DPIW is the lead agency in Tasmanian that is responsible for the management of introduced marine species. This document reviews information on the Derwent Estuary distribution and issues arising from introduced marine and intertidal species. The review focuses several species: Northern Pacific seastar (*Asterias amurensis*), Japanese seaweed 'wakame' (*Undaria pinnatifida*), European Clam (*Varicorbula gibba*), European green crab (*Carcinus maenas*), which are identified as 'marine pests' for which there are 'National Control Plans'. The review also focuses on several other introduced species, which we have some knowledge of their distribution and impacts (or potential impacts) in the Derwent Estuary. These species include: Rice grass (*Spartina angelica*), Toxic algal blooms (*Gymnodinium catenatum*), Pacific Oyster (*Crassostrea gigas*), and New Zealand screw shell *(Maoricolpus roseus).*

A much briefer review component includes comments on the New Zealand seastar *(Patiriella regularis,* New Zealand half crab (*Petrolisthes elongates*), and other species, such as: *Chilton glaucus, Cancer novaezelandiae, Halicarcinus innominatus, Corophium acherusicum, Corophium insidiosum, Caprella acanthogaster, Theora lubrica*, *Raeta pulchella, Myxicola infundibulum, Codium fragile* ssp. *Tomentosoides, Membranipora membranacea, Ascidiella aspersa*, *Ciona intestinalis, Bougainvillia muscus*, *Clytia hemisphaerica, Plumularia setacea*, *Cordylophora caspia*, *Ectopleura dumortieri*, *Phialella quadrata*, *Sarsia eximia, Turritopsis nutricula, Euchone limnicola, Salmo trutta*, *Oncorhynchus mykiss, Grahamina gymnota* and *Grahamina varium.* The lack of attention towards these species in this review should not signify an assumed low level of impact to the estuarine environment. Instead, this more likely highlights the paucity of information on their Derwent Estuary distributions and environmental impacts.

This review document is intended to raise awareness of the issues surrounding introduced marine and intertidal species management. It is intended that this document will assist the Derwent Estuary Program engage in discussion with DPIW, key researchers and stakeholders to enable the development of a 'priority action plan' for introduced marine and intertidal species management in the Derwent Estuary. A priority action plan will hopefully assist in drawing support for the necessary work of preventing new marine pest infestations to the Derwent Estuary, preventing translocation of existing pests, establishing achievable objectives for the control/eradication of existing pests (where appropriate), encourage research into and implementation of effective and appropriate control or eradication options, and the creation and dissemination of educational materials to assist with introduced species management.

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APPENDIX 1. Acronyms for the "National System" of marine pest management in Figure 1.

AQIS	Australian Government Australian Quarantine and Inspection Service
CCIMPE	Consultative committee on introduced marine pest emergencies
CSIRO	Australian Commonwealth Scientific and Research Organization
DAFF	Australian Government Department of Agriculture, Fisheries and Forestry
DEWH	Australian Government Department of the Environment, Water, Heritage and the Arts
DITRDLG	Australian Government Department of
DPIW	Tasmanian State Government Department of Primary Industries and Water
EMPPlan	Australian Emergency Marine Pest Plan
HLG	High Level Official Working Group
IGA	Intergovernment Agreement
NIMPCG	National Introduced Marine Pests Coordination Group

Appendix 2.; CCIMPE TRIGGER LIST SPECIES

CONSULTATIVE COMMITTEE ON INTRODUCED MARINE PEST EMERGENCIES

CCIMPE TRIGGER LIST SPECIES Scientific Name/s		**Common Name/s**
Species Still Exotic to Australia		
1 *	*Eriocheir* spp.	Chinese Mitten Crab
2	*Hemigrapsus sanguineus*	Japanese/Asian Shore Crab
3	*Crepidula fornicata*	American Slipper Limpet
4 *	*Mytilopsis sallei*	Black Striped Mussel
5	*Perna viridis*	Asian Green Mussel
6	*Perna perna*	Brown Mussel
7 *	*Corbula* (*Potamocorbula*) *amurensis*	Asian Clam, Brackish-Water Corbula
8 *	*Rapana venosa* (syn *Rapana thomasiana*)	Rapa Whelk
9 *	*Mnemiopsis leidyi*	Comb Jelly
10 *	*Caulerpa taxifolia* (exotic strains only)	Green Macroalga
11	*Didemnum* spp. (exotic invasive strains only)	Colonial Sea Squirt
12 *	*Sargassum muticum*	Asian Seaweed
13	*Neogobius melanostomus* (marine/estuarine incursions only)	Round Goby
14	*Marenzelleria* spp. (invasive species and marine/estuarine incursions only)	Red Gilled Mudworm
15	*Balanus improvisus*	Barnacle
16	*Siganus rivulatus*	Marbled Spinefoot, Rabbit Fish
17	*Mya arenaria*	Soft Shell Clam
18	*Ensis directus*	Jack-Knife Clam
19	*Hemigrapsus takanoi/penicillatus*	Pacific Crab
20	*Charybdis japonica*	Lady Crab
Species Established in Australia, but not Widespread		
21 *	*Asterias amurensis*	Northern Pacific Seastar
22	*Carcinus maenas*	European Green Crab
23	*Varicorbula gibba*	European Clam
24 *	*Musculista senhousia*	Asian Bag Mussel, Asian Date Mussel
25	*Sabella spallanzanii*	European Fan Worm
26 *	*Undaria pinnatifida*	Japanese Seaweed
27 *	*Codium fragile* spp. *tomentosoides*	Green Macroalga
28	*Grateloupia turuturu*	Red Macroalga
29	*Maoricolpus roseus*	New Zealand Screwshell

Holoplankton Alert Species * For notification purposes, eradication response from CCIMPE is highly unlikely		
30 *	*Pfiesteria piscicida*	Toxic Dinoflagellate
31	*Pseudo-nitzschia seriata*	Pennate Diatom
32	*Dinophysis norvegica*	Toxic Dinoflagellate
33	*Alexandrium monilatum*	Toxic Dinoflagellate
34	*Chaetoceros concavicornis*	Centric Diatom
35	*Chaetoceros convolutus*	Centric Diatom

Appendix 3. Summary of the efficacy and feasibility of currently available management *Asterias* (*Asterias* NCP 2008) (Note that potential control options such as genetic control that are under development or are considered environmentally unacceptable are not included).

Method	Likely Efficacy	Feasibility	Environmental/public concerns
1. Directly targeting *Asterias*			
Diver removal	Potentially effective given adequate intensity of diving effort. Likely to require ongoing removal to maintain low *Asterias* densities.	Feasible at shallow depths (< 12 m) at small-moderate spatial scales* (e.g. aquaculture leases, localised high density populations associated with wharf structures). Initial and ongoing efforts will require significant expenditure.	Minimal environmental concerns.
Trapping	Partially effective for high density populations. Likely to require ongoing removal to maintain effectiveness.	Feasible at all depths. Initial and ongoing efforts will require significant expenditure.	Minimal environmental concerns. By-catch release unharmed.
Biological control *-Enhancement of native predator populations*	Requires understanding of native predators of *Asterias*. Likely efficacy remains unknown.	Practical application remains unknown.	Would require research to ensure impacts on non-target species are minimal.
2. Habitat management			
Food supply *-reduce abundance of mussels associated with artificial structures*	Likely to be effective in reducing formation of high density *Asterias* aggregations and subsequent reproductive output.	Feasibility remains unknown. Unlikely to be a practical, readily available method of removing food organisms (e.g. mussels).	'Cleared' pylons could provide habitat for other pest species.
Environmental rehabilitation	Efficacy remains unknown. Efficacy depends on the link between human mediated activity and *Asterias* invasion success.	Feasibility will depend upon the human activities concerned and remains unknown an.	Minimal environmental concerns.
3. Impact Mitigation			
Barriers for aquaculture	Potentially effective method to exclude adult *Asterias* from aquaculture areas.	Only likely to be feasible on small spatial scales*. Would require significant investment to build and maintain barriers.	Minimal environmental concerns.
Modify aquaculture practices -e.g. Modify timing of commercial operations to minimise interaction between *Asterias* larvae stock/equipment.	Likely to be effective.	Requires understanding of the abundance and distribution of *Asterias* larvae. Likely to incur labour costs and result in lost productivity.	Minimal environmental concerns.

*Small spatial scale = < 1000 m^2; moderate spatial scale = 1000 – 10 000 m^2; large spatial scale = > 10 000 m^2.