FINAL REPORT FOR THE AUSTRALIAN GOVERNMENT DEPARTMENT OF THE ENVIRONMENT AND HERITAGE

CONTROLLING THE NORTHERN PACIFIC SEASTAR (*ASTERIAS AMURENSIS*) IN AUSTRALIA

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Helping Communities Helping Australia
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The introduction of non-indigenous species can act as vectors for new diseases, alter ecosystem processes, reduce biodiversity (Vitousek et al. 1997), cause major economic loss (Mack et al. 2000; Bax et al. 2001) and disrupt human activities (Vermeij 1996). In 1999, a growing concern about the potentially devastating impacts of introduced marine pests, led the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Ministerial Council on Forestry, Fisheries and Aquaculture (MCFFA) to agree to establish the National Taskforce on the Prevention and Management of Marine Pest Incursions. The Taskforce was instructed to report to the Ministerial Councils in 1999, through their respective standing committees, with recommendations both for interim improvements and for longer-term reforms to the national arrangements for the prevention and management of introduced marine pests. The Taskforce report is underpinned by the principle that prevention through vector control is the best solution for managing marine pests because eradication programs can be very costly and controversial (Myers et al. 2000), and are not successful for the majority of non-indigenous species (Carlton 2001)[1]. Prevention management minimises the risk of a species establishing by targeting responses to the early parts of the invasion process as depicted in Table 1 (Kolar and lodge, 2001). This preventative approach is also consistent with international policy of the management of non-indigenous species (Bax et al. 2001; United States National Invasive Species Council 2001).

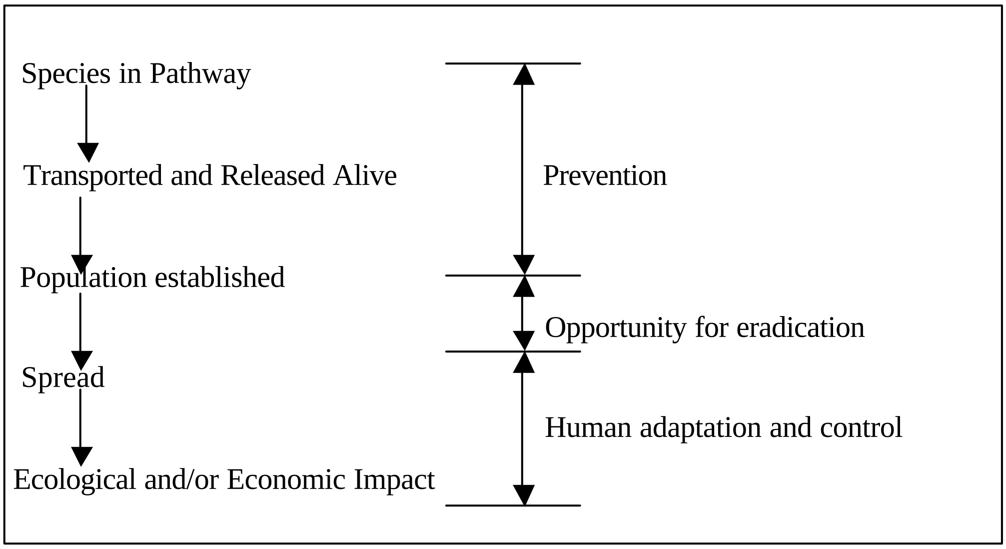
A practical application of the preventative approach is the world's first *National Control Plan* for a marine pest, the Northern Pacific Seastar (hereafter referred to as *Asterias*), which is included in the Taskforce report. *Asterias* is a voracious predator that threatens Australia's southern ocean waters from Sydney to Perth out to a depth of at least 100m. This area includes a large portion of the extensive continental shelf off southern Australia including World Heritage Areas, Ramsar Sites and marine protected areas. In recognition of the environmental and economic risks posed by *Asterias*, it is an important example species for developing Australia's first National Control Plan. The *National Control Plan* is a coherent, strategic plan to minimise the rate of spread of the seastar and reduce its impacts on Australia's marine biodiversity and industries. The *National Control Plan* aims to prevent the continued spread of the Seastar in Australian waters; permanently reduce or minimise the impacts of, if not eradicate, the seastar; improve the knowledge of the impacts; communicate the results,

[1] In October 2003 the Natural Resource Management Ministerial Council endorsed recommendations to address key governance, legislative and funding arrangements required to implement a National System for the Prevention and Management of Marine Pest as recommended by the National Taskforce.

effectively coordinate control activities and provide for periodic evaluations. Australian Governments adopted the *National Control Plan* in 2000 (Joint SCC/SCFA Taskforce 1999).

Table 1 – Process of species invasion

Invasion Process **Management response**



From Kolar & Lodge 2001

Consistent with the *National Control Plan for the Northern Pacific Seastar*, this project addresses three issues:

Chapter 1: Temporal and spatial patterns of larval abundance in Port Phillip Bay and the Derwent River Estuary that affect the risk posed by ballast water transfer.

Chapter 2: Characteristics of human-mediated vectors, other than ballast, that pose risks of spreading exotic species across southern Australia.

Chapter 3: Identification and assessment of practical options for better early warning systems to detect *Asterias* and other exotic species introductions to new locations.

The expected outcome of this project will be a reduction in the risk for the Seastar to marine industries and the environmental values of Australia's southern ocean coastal waters, including World Heritage, Ramsar and Marine Protected Area values. This is expected to result in reduced short and long term environmental and economic costs through limiting further secondary invasions, improved targeting of management efforts by the community, private and government sectors and an improved early response capacity.

2. TEMPORAL AND SPATIAL PATTERNS OF LARVAL ABUNDANCE IN PORT PHILLIP BAY AND THE DERWENT RIVER ESTUARY THAT AFFECT THE RISK POSED BY BALLAST WATER TRANSFER

INTRODUCTION

Historically, ballast water in the tanks of ocean going vessels has been considered to be a significant vector for transporting marine pests (Carlton and Geller 1993). In the early 1990s, for example, at least 14 species were known to have been introduced to Australia by this vector (Jones 1991). Voluntary exchange of ballast water while vessels travel over oceanic waters > 2000m is currently the main management tool to prevent marine pest invasions from this vector in Australia and worldwide (IMO 2003). In implementing *a National System for the Prevention and Management of Marine Pest Incursions*, Australian Governments have agreed that the ballast water risk from vessels operating between domestic ports will be managed.

Within Australia, the Ballast Water Decision Support System (BWDSS) is used to determine the biological risk associated with ballast water movements. The aim of the BWDSS is to identify ballast water that if discharged would lead to a high risk of a target marine pest species being established at a new a location. The risk is related to the route taken – vessels drawing ballast from an infected port and journeying to an uninfected port can pose a risk. Further assessments can then be made based on pest biology and the suitability of the uninfected port for invasion. Ballast taken up from a 'temperate' port and discharged in a 'tropical' port is also not considered 'high risk' because of habitat unsuitability. Ballast drawn outside of pest spawning periods may also not constitute a 'high-risk' since there are no larvae to be taken up in ballast water and subsequently transported. Operating during these periods in which larvae are either absent or in low densities, "ballast windows", help refine risk management options available for vessels taking up ballast water in an infected port. The focus of this project is to consider a 'ballast window' approach for *Asterias*, for possible inclusion in the Australian BWDSS. This issue is extensively discussed, by Hayes and Hewitt (2002) for example.

Spawning periods for *Asterias*

Phase shifts in the spawning period of *Asterias* from the northern Hemisphere suggest photoperiodic regulation of spawning but temperature also plays a regulatory role (Byrne et al. 1997). Spawning coincides with lowest water temperatures in Japan (winter/early spring) and Australia (late winter/spring) (Byrne et al. 1997). Spawning also coincides with lowest water temperatures in Sendai

Bay, Japan (January to March in water temperatures 8.4-12.3^0 C) and is slightly later in Mutsu Bay, Japan, when its cooler (late February to early May at 5-10^0 C) (Kim, 1968). Factors other than photoperiodic temperature also appear to play a role in the timing and length of spawning. Hatanaka and Koska (1958) found that not all oocytes developed at the same rate in Japanese waters indicating multiple spawning events but no such evidence was found from Mutsu Bay (Kim, 1968). Studies by Fenaux (1982) shows that seastars have the ability to extend their planktonic lives until settlement conditions are favourable. This is corroborated by (Byrne et al. 1997) who found the presence of similar sized juveniles from different cohort years indicating that larvae may spend an extended period in the plankton, with the potential overlap of generations. Such extended larval periods and coincidence with local temperature minimums indicate that there is the potential for significant temporal and spatial variability in the onset of spawning and larval duration of *Asterias*. This may influence the extent and usefulness of the 'ballast window' as applied in a risk-based system such as the BWDSS.

Potential variability in the onset and duration of the ballast window in temperate Australia

Asterias distribution is currently restricted to two main sites of infection in Australia: the Derwent Estuary and Port Phillip Bay. Both sites receive shipping traffic, particularly Port Phillip Bay, which is considered a hub port for both international and domestic shipping (Hewitt et al. 1999). However, the sites are ~600km apart and have contrasting environments, which may influence the onset and duration of the ballast window. The Derwent Estuary is relatively small (70km^2) and deep (up to 44m) and receives a consistently high freshwater input from the Derwent River. The water exchange time for the entire estuary is ~ 10-15 days depending on river flow. By comparison, Port Phillip is a large (~1930km^2), sheltered and relatively shallow embayment (mostly < 8m) that receives freshwater input from a number of rivers. Residence time, which influences larval retention time for *Asterias* is much longer in Port Phillip Bay than the Derwent Estuary, at approximately 10-16 months. Water temperatures are ~1^{0}C warmer in Port Phillip Bay than the Derwent Estuary (http://www.aodc.gov.au/) that may cause a slight lag in the onset of *Asterias* spawning and shorter spawning duration.

The aim of this project was to determine the degree of variability in the spawning and larval duration of *Asterias* in Port Phillip Bay and the Derwent Estuary. Significant temporal variability at sites in the onset and duration of spawning would suggest that "ballast windows" would need to be determined on an annual basis or extended over a very long time period. As both Port Phillip Bay and the Derwent Estuary contain native species that overlap the larval period of *Asterias*, a gene probe for *Asterias* has been used to positively identify its presence in samples (Deagle et al. 2003). On the onset or end of the larval period, *Asterias* larval densities may be sufficiently low to be considered a low-risk for further infection by transported ballast water. In this context, quantitative estimates of density allow further evaluation of the risk of entraining *Asterias* in ballast water and transporting it to new sites.

METHODS

For this study, all samples for *Asterias* larvae have been collected from the Derwent Estuary and Port Phillip Bay waters from May 2002 and up to January 2003 in the Derwent Estuary. Sampling methods and analysis are described in Johnson et al (2004). Briefly, in Port Phillip Bay, water samples were collected fortnightly in 2002 during spawning from three piers: St Kilda, Ann Street Pier and Gellibrand Pier. The presence of *Asterias* in Port Phillip Bay samples was confirmed using the gene probe. In the Derwent Estuary, water samples were collected in 2001 and 2002 from Sullivans Cove, Port Hobart in the upper reaches of the Estuary (Fig 1). Only the Tasmanian samples were sorted and enumerated for larval density and the presence of *Asterias* was positively identified with the gene probe (for details see Johnson et al 2004).

RESULTS

At Port Phillip Bay sites, *Asterias* larvae were first positively identified in the water column in late May of 2002 and last detected in late October 2002 (Table 1). Spawning is therefore likely to have occurred in early to mid May with a larval duration to early November. Likewise in 2002, *Asterias* larvae were first detected in Sullivans Cove in late May (1.6 larvae m^{-3}), but early brachiolaria stages were found as early as mid June, suggesting that some spawning occurred as early as April (Johnson et al 2004). However, larvae concentrations in April were below the detection limits of the gene probe. Peak spawning occurred in August 2002 and larvae were present in the water column until mid December (0.3 larvae m^{-3}) (Fig. 1). Early-stage larvae were present from June until October indicating a protracted spawning season with multiple spawning events (Johnson et al 2004). Densities of *Asterias* larvae were comparatively low throughout most of the 2002 spawning season, with a peak of 29.7 larvae m^{-3} in late August, followed by a sharp decline, possibly also due to flooding events (Johnson et al 2004). These results indicate a slightly more protracted larval period for *Asterias* in 2002 in the Derwent River (May – December) than in Port Phillip Bay (May – November).

Table 2 – Gene probe analysis of *Asterias* presence in Port Phillip Bay for the 2002 spawning period

Date	Shoulder period	St Kilda Pier	Ann street Pier	Gellibrand Pier

2/5	1	Not detected	Not detected	Not detected
15/5	1	Not detected	Not detected	Not detected
29/5	1	Detected	Detected	Detected
12/6	1	Detected	Detected	Not sampled
26/6	1	Detected	Detected	Detected
9/7	1	Detected	Detected	Detected
24/7	1	Detected	Detected	Detected
1/10	2	Detected	Detected	Detected
15/10	2	Detected	Detected	Detected
30/10	2	Detected	Detected	Not detected
13/11	2	Not detected	Not detected	Not detected
25/11	2	Not detected	Not detected	Not detected
11/12	2	Not detected	Not detected	Not detected

In contrast in Sullivans Cove in 2001, the larval duration for *Asterias* was much shorter than in 2002. Larvae were first found in the water column at Sullivans Cove from early August 2001 until late November, with a temporary disappearance in early September after a massive peak in river flow (Fig. 1). Immediately prior to and following this peak, the concentration of larvae at Sullivans Cove was 34 larvae m^{-3} and 0 larvae m^{-3} respectively. Similarly, larval densities in Sullivans Cove fell to very low levels after peaks in river flow in 2002 (Fig. 1). The peaks in larval abundance (19-51.5 m^{-3}) during the 2001 season in August and September were on either side of the flood event, and were composed largely of early larval stages suggesting recent spawning events (Johnson et al 2004). Early larval stages are those closest to the spawning event (release of the sperm and eggs).

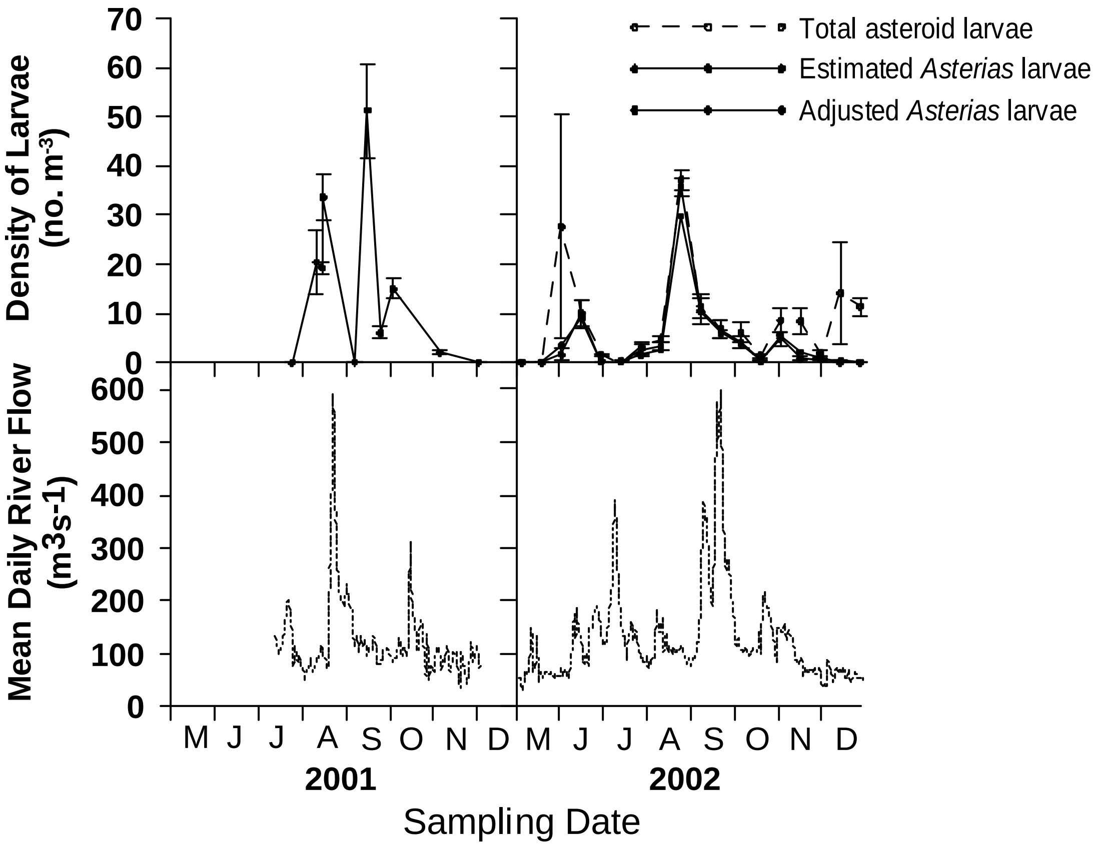


Figure 1 - Mean density (N m^{-3} $\pm$ SE) of *Asterias* larvae in Sullivans Cove (top) and mean daily flow rate in the Derwent River determined at Meadow Bank (bottom) in 2001 (23 July - 1 December; left) and 2002 (3 May - 27 December; right). Note that 'estimated' larvae are those identified on the basis of morphology, while 'adjusted' larvae are adjustments to initial estimates based on genetic identification of individual larvae. Asteroid larvae that were not *Asterias* were not enumerated in 2001, and genetic confirmation of identifications of larvae (as *Asterias* or otherwise) were not undertaken in 2001. Data from Johnson et al (2004).

DISCUSSION

Asterias grows rapidly, is highly fecund, forms dense populations, has a very broad diet, and appears to have few, if any, significant native enemies in Australia (McEnnulty et al. 2001). Experiences in Port Phillip Bay suggest that, even if discovered at low densities, once a population is established there is little chance for a successful eradication (Parry et al. 2000). A key management action applied to the seastar in the *National Control Plan* is to prevent its spread to susceptible Australian waters through vector control. In this context, the application of an *Asterias* "ballast window" in the BWDSS can refine preventative measures taken in respect to ballast water, the vector responsible for the seastar introductions to Port Phillip Bay and the Derwent Estuary (Hewitt et al. 1999). The onset and duration of spawning and larval densities during spawning, and year to year variations are important issues in assessing the tractability of the use of a 'ballast window' in the Australian BWDSS.

Onset of spawning and larval duration in Port Phillip Bay and the Derwent Estuary

In 2002, larval samples collected from Port Phillip Bay and positively identified with an *Asterias* gene probe indicate an onset of spawning in early May, and larval duration up to the end of November (Table 1). This is earlier than predicted by Parry and Cohen (2001) who used gonad indices to estimate the onset of spawning in early June of 2001 and early July of 1999 (Table 3). Differences in the onset of spawning shown for this study and Parry and Cohen (2001) may be due to sampling techniques (indirect measures – gonads versus direct measures – gene probe). However, the later onset of spawning in 1999 compared to 2001, both predicted by gonad indices, suggest that there is annual variability in the onset of spawning in Port Phillip Bay. Early spawning appears to coincide with lower water temperatures early in the season. In 2002, spawning was first noted with cooler May sea-surface temperatures, than in 2001 when equivalent temperatures and spawning first occurred in June (http://www.earthsci.unimelb.edu.au/~awatkins/temps.html). Larvae have not been recorded past December, possibly because of increasing water temperatures (Table 3). The longest larval duration expected for *Asterias* from results to date, is between May and December in Port Phillip Bay (Table 3). This suggests that there is the potential for a minimum four-month ballast window to be applied between January and April.

Table 3 - Larval duration periods recorded for *Asterias* in Port Phillip Bay. Shaded areas – larvae detected in the water column

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Nov	Dec	Jan
1999[3,#,]							■	■	■	■	■	
2001[3,#]						■	■	■	■	■	■	
2002[1,*]					■	■	■	■	■	■		

1 – This study; 2 – Johnson et al (2004); 3 – Parry and Cohen (2001); 4 – Koch and Johnson (in prep); Sutton and Green (unpublished ms); 6 – Byrne et al (1997). * – Identification by gene probe; &– morphological identification, $ - morphological identification with gene probes used to verify a sample subset; # –gonad indices

Table 4 - Larval duration periods recorded for *Asterias* in the Derwent Estuary. Shaded areas – larvae detected in the water column

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Nov	Dec	Jan
1993-1994[6, #]							■	■	■	■	■	■
1995-1997[5, $]						■	■	■	■	■	■	■
1999[4, &]						■	■	■	■	■	■	
2001[1,2*,&]								■	■	■	■	
2002[1,2,*,$]				■	■	■	■	■	■	■	■	

Local factors such as river flow clearly affect the larval densities of *Asterias* and possibly its onset and duration (Johnson et al, 2004). There appears to be a greater similarity in the length of larval periods between Port Phillip Bay and Derwent Estuary in the same years that larval duration was estimated (1999- 2002) than between years in the same location (Table 3 and 4). This suggests that regional factors, operating at the scale of both locations, possibly water temperatures, may have a greater influence on the onset of spawning and its duration than highly localised factors such as river flow or embayment topography.

The earliest onset of spawning (April 2002) recorded for any year in the Derwent Estuary was in this study, with larvae persisting in the water column till mid December (Table 4). However, earlier studies by Sutton and Green (unpublished ms) indicate that *Asterias* larvae, positively identified with gene probes, can be present as late as January (Table4). These results suggest a more protracted larval period for *Asterias* in the Derwent Estuary (May – January) than in Port Phillip Bay (May – November), possibly because the water remains colder for longer. Alternatively, greater inter annual variability may be captured in the Derwent Estuary because of the greater number of studies conducted. Based on all available data for the Derwent Estuary, it appears that the ballast window may only be available for three months between February and April (Table 4).

Discussions and conclusions

An analysis of Lloyd's shipping data provides an indication of the potential management implications (assumed mandatory exchange of ballast water as the management option) that can be gained if “ballast windows” are applied to all vessels (domestic and international) that departed Port Phillip Bay and the Derwent Estuary in 2002. This also assumes that the recipient ports are uninfected with *Asterias* and that the infected port only contains *Asterias*. In 2002, the Port of Melbourne received 2521 ship visits that carried ballast (Hayes and Dunstan, unpublished data). Approximately one third of these vessels (836) arrived and departed from Melbourne during the potential ballast window for *Asterias* (1 February – 30 April). In a recent demonstration project conducted at the Port of Hastings (Westernport, Victoria), mandatory exchange of high-risk ballast water for short trips were calculated to cost ~ \$4000-\$51 000 per vessel (Meyerick and Associates Pty Ltd 2003). If these figures are applied to the Port of Melbourne, then in 2002 between \$3-43 million could be saved by refining risk assessments by inclusion of a ‘ballast window’. The Port of Hobart is much less trafficked than Melbourne, with only 163 ballast carrying vessels departing Hobart in 2002. Of these, 37 operated during the ballast window period (1 February – 30 April). However, avoiding ballasting during this larval free- period could still save a substantial $0.1-2 million based on the same costs estimated for the Port of Melbourne.

While these examples are provided for illustrative purposes only they indicate scale of cost savings that may arise though a 'ballast window'. However, the implications for ports, such as the Port of Melbourne, that contain many of the target pest species currently listed in the BWDSS (Hewitt et al. 2004) requires consideration. The diversity of species present may mean the utility of a 'ballast window' is diminished as result of overlapping periods of larval duration. However, decisions can be made on a case-by-case basis on the cost effectiveness of using an *Asterias* ballast window for particular routes originating from infected ports (Melbourne, Geelong and Hobart) now that the onset and maximum duration of the larval spawning period is better resolved.

The density of *Asterias* and risk status of ballast water

The total number and frequency of pests arriving at the same time is termed the "propagule pressure" and has been directly linked to the likelihood of establishment when environmental conditions at the recipient site are conducive to the survival of adult or other life-stages (Underwood and Fairweather 1989; MacIsaac et al. 2002; Occhipinti-Ambrogi and Savini 2003). Small inoculations are less likely to establish due to stochasticity and allee effects – reproduction density, etc (Drake et al. 2001). The initial density of *Asterias* drawn in ballast at the donor port dictates the propagule pressure on the recipient port and should therefore be considered when assessing the risk status of the ballast to be discharged. It may be cost and environmentally effective to extend *Asterias* ballast window based on an acceptable larval density threshold.

For this study, the density of *Asterias* at Sullivans Cove was ten fold higher during the peak spawning period of August – September than in the beginning and end of the spawning (shoulder periods) in May and December (Fig. 1). Likewise, peak spawning in Australia has always occurred in August/September in Port Phillip Bay and the Derwent (Byrne et al. 1997; Parry and Cohen 2001; Johnson et al 1994). Ballast water drawn during this peak spawning period will represent a greater propagule pressure, and therefore is of greater risk, than ballast water drawn on shoulder periods.

Currently however, the relationship between uptake density and the "risk" of ballast water translocating marine pest is not considered in the 95% exchange requirements where this is the option used to manage risks. Ballast water can be discharged if vessels have completed a 95% exchange so that only 5% of the original tank volume remain (AQIS, 2001). For example, if a vessel draws ballast at the maximum densities ever recorded for *Asterias* in the Derwent (~1000 larvae m^{-3}) (Sutton and Green 2002), the propagule pressure in the discharged ballast after 95% exchange (5% of $1000m^{-3}$ = 50 larvae m^{-3}) will be equivalent to the maximum densities in this study (52 larvae m^{-3}) without exchange. If the propagule pressure at 50 larvae m^{-3} is sufficient to establish a population, then the exchange undertaken by the vessel carrying initial densities of 1000 m^{-3} does not mitigate the risk of further spreading the pest and does not serve the management purpose.

Hence, agreement on a threshold density for *Asterias* in the port waters, which once exceeded, would require management of ballast water risk becomes an important refinement in assessing environmental and cost effectiveness of management options. However, we currently do not know what the threshold density of *Asterias* that is sufficient to apply enough propagule pressure to the recipient port to establish a population. Further, the susceptibility of the recipient port may also change with time (e.g (Occhipinti-Ambrogi and Savini 2003)). A conservative approach may be to consider *Asterias* densities at the shoulder periods of spawning to be the lowest risk. In this study larval densities on the shoulder periods were ~5 larvae m^{3}. If 95% exchange is performed, this would result in a density threshold of ~0.25 larvae m^{3} being discharged into the recipient port.

If such an approach based on a threshold density were acceptable then port waters would have to be monitored on a fortnightly to monthly basis. This could be achieved quickly and cost-effectively using the calibrated *Asterias* gene probe with real-time Polymerase Chain Reaction (PCR) equipment (Nic Bax, per comm.). There may be significant economic returns on investing such technology in reducing the number of mandatory exchanges for vessels originating from highly trafficked, *Asterias* infected ports, such as Melbourne. This approach could be complimented by reducing the number of adult *Asterias* concentrated in hotspots around wharves and marinas (Johnson et al, 2004). Modelling results indicate that targeting hotspot populations will significantly reduce larval production in the Derwent estuary, and surrounds. This in turn will reduce risk of further recruitment of *Asterias*, and extend the duration at which the larval threshold density can be applied as a criteria for refining the assessment of risk.

3. CHARACTERISTICS OF HUMAN-MEDIATED VECTORS, OTHER THAN BALLAST, THAT POSE RISKS OF SPREADING EXOTIC SPECIES ACROSS SOUTHERN AUSTRALIA

INTRODUCTION

Asterias is thought to have been introduced to Tasmania as larvae in ballast water (Rainer 1995). The seastar has since spread to another major port complex – Port Phillip Bay (Hewitt et al. 2004). As the Bay is a major transport hub and considering the highly fecund, dispersive life history of *Asterias,* it has considerable potential to establish new populations elsewhere in temperate Australia (Byrne and Morrice, 1997). Experiences in Port Phillip Bay suggest that, even if discovered at low densities, once a population is established there is little chance for a successful eradication (Parry et al. 2000). A key management action applied to *Asterias* in the *National Control Plan* is therefore to prevent its spread to susceptible Australian waters through vector control.

At present, it is not known whether *Asterias* or other seastars are readily entrained in non-ballast vectors although the discovery of adult seastars in the water intake ('sea chest') of a vessel suggest that other methods are possible (Thresher 2000). The diversity of marine exotic species found in seemingly uncontaminated habitats and not connected to a commercial port illustrates how important non-ballast vectors are for translocating species (Wasson et al. 2001). The European shore crab was introduced from the discard of seaweed used to wrap bait (Carlton 2001). This seemingly insignificant vector corroborates the point that an apparently insignificant vector may not be a minor one if it leads to an introduction (Carlton 2001). This study focuses on determining the likelihood of entraining *Asterias* into non-ballast, human-mediated vectors within three broad types: vessel hulls, fishing gear and aquaculture gear, for translocating *Asterias*. The aim is to identify the vectors' effectiveness for entraining *Asterias*, to a level that will allow their prioritisation for developing and implementing management intervention as outlined in the *National Control Plan*. Ballast water is not included for the following reasons: its management already involves broad Asterias transfer probability estimates; significantly improving these would be resource intensive; relatively few management options are currently available and improved estimates are unlikely to affect technological development rates.

There are at least two-components to be considered for vector management – entrainment (the passive uptake or active attachment of an organism to a vector) and translocation (the transport of an organisms to a new locality by a vector) (Kinloch et al. 2003). A companion study by the Bureau of Rural Sciences provides insight into the translocation of marine pests, including *Asterias* (Kinloch et al. 2003). Vectors have been ranked on their likelihood of entraining *Asterias*, but experts opinions would benefit from observational data (Dommisse and Hough (eds), 2002). For this project, qualitative data has been collected from the literature and interviews with stakeholder groups relating to each vector group (aquaculture, fishing gear and ship hulls) in areas of major *Asterias* infection in Australia (Port Phillip Bay, and southeast coast of Tasmania). Each vector group is dealt with separately.

AQUACULTURE STOCK AND GEAR

Marine-based aquaculture activities are considered "hotspot" areas for seastar congregations because of the availability of food (Morrice 1995; Martin and Proctor 2000; NIMPIS 2002). In Japan, farms that cultivate shellfish, the preferred seastar food, commonly suffer considerable loss of stock by predation to *Asterias* (Hatanaka and Kosaka 1959; NIMPIS 2002). A conservative estimate of the damage to marketable shellfishes caused by *Asterias* in Tokyo Bay in 1954 amounted to 400 million yen (Kim 1968). Stock losses can be due to adults dimbing onto farming gear (Spencer 1991) or predating on dislodged stock (Rodhouse et al. 1985). However, the greatest stock losses appear to be to post-larvae seastars that settle onto growing ropes or spat collecting devices (Spencer 1991; McLoughlin and Bax 1993). In the northern Hemisphere *Asterias* has been sufficient to prompt the use of novel control methods (Lawrence et al. 1999). These include a dredge like "mop" and suction dredges to remove seastars from oyster beds (Galtsoff and Loosanoff 1939). In northern Japan, physical removal of *Asterias* is routinely practiced as part of a rotational scallop enhancement and culture program (Ito 1991).

The close association of seastars with aquaculture in their native regions suggests a real potential for their entrainment and transport to new areas in Australia. A diverse range of aquaculture industries occurs in both areas of infection by *Asterias*: the waters of southeast Tasmania and Port Phillip Bay, Victoria (Fig. 2). Species currently farmed in Tasmania include abalone, blue mussels, Pacific oysters, rock lobsters, and salmon and sea horses (Larcombe et al. 2002). There have also been a number of special lease areas granted for the experimental culture of scallops and sea urchins (Larcombe et al. 2002). In Tasmania as of 2002 there were 28 active salmon permits. Shellfish leases include 89 devoted to the pacific oyster and 15 to blue mussels. There are ~150 separate marine farms with a total area of 1,500ha in Tasmania, mostly in the cooler waters of the South East (Aquaculture Research Advisory Group, 1999).

Most of the aquaculture in Victoria takes place in the waters of Port Phillip and Western Port Bays. The dominant species farmed in the blue mussel (4000-5000 tons pa) (Fisheries Victoria, 2001). The industry consists of 23 producers based on Port Phillip Bay and Western Port Bay but is likely to increase to service the foreign market and by the recent allocation of more waters designated for aquaculture. Abalone has attracted the bulk of investment dollars and is expected to expand significantly in the future to become the largest sector of the Victorian aquaculture industry (Fisheries Victoria, 2001).

Aquaculture (live oysters trade) has been implicated in the transport of the other introduced asteroids to Australia: *Patiriella regularsis* and *Astrostole scabra* from New Zealand (O'Hara 1995). However, modern aquaculture practices have greatly improved so that the chance of entraining seastars in stock has significantly reduced. While accidental introductions through relocation of equipment continue to be a problem (Hewitt and Martin 2001), these should be minimised once the *National Policy for the Translocation of Live Aquatic Organisms* is fully implemented (Ministerial Council on Forestry, Fisheries and Aquaculture 1999).

There have been reports of very large numbers of *Asterias* in scallop spat collector bags and suspended 'grow out 'cages near Triabunna, Tasmania (McManus and Proctor 2001). *Asterias* have been reported from mussel long-lines in Port Phillip Bay (Garnham, 1998 in Goggin (1998), Talman et. al, 1999) and oyster trays in Pipe Clay Lagoon, Tasmania (Martin and Proctor 2000). The size of the seastars varied from recently settled juveniles (3-4cm in diameter) on mussel lines to pre-productive adults in oyster trays. It is believed that, in all cases, settlement from plankton directly onto the different gears used is the most likely origin of the seastars (Martin and Proctor 2000). This is corroborated by Hickman (1998) findings that aquaculture farmers surveyed in Port Phillip Bay in 1998 could not catch *Asterias* in specially designed benthic traps but they found numerous juveniles on nearby mussel ropes. In Pipe Clay Lagoon, both native and *Asterias* are actively removed from aquaculture gear (DPIWE 1998).

For this study, telephone surveys were conducted between July 2002 and May 2003 of aquaculture farmers operating in southeast Tasmania and Port Phillip Bay to document the incidence of entrainment of *Asterias* into aquaculture gear and stock. Personal communications are listed in Appendix A. Marine farmers were all asked a standard set of questions, but details were sought when a seastar entrainment was reported (Appendix B). Altogether, 20 farms were surveyed in both Victoria and Tasmania, with representatives from every aquaculture type contacted (Table 5). Each fishery is dealt with separately.

- ***Salmoniids***

The main salmonid cultures in Tasmania is the Atlantic salmon (*Salmo salar*) (Aquaculture Research Advisory Group, 1999). Atlantic salmon fry are hatched and grown in freshwater nurseries to around 70g in weight. The salmon are then transported to seacages and spend around 30 months growing to the market size of 3.5 – 4.5kg (National Oceans Office, 2002). The whole process takes around 30 months due to the extremely fast growth rates under Tasmanian conditions (Aquaculture Research Advisory Group, 1999). Around two thirds of salmon production is partially processed (chilled) and the remaining product is used for value adding to products. The majority is sold in Australia with twenty five percent sold to Asia (National Oceans Office, 2002). Most salmon farming occurs in Macquarie Harbour and the D'Entrecasteaux Channel but some salmon are cultured on the north coast of Tasmania as well (Larcombe et al. 2002). The majority of rainbow trout (*Oncorhynchus mykiss*) are produced in Macquarie harbour on the west coast (Aquaculture Research Advisory Group, 1999).

Many seastars (both native and *Asterias*) have been observed on the benthos below the floating seacages, but have not been reported on a rope or the cage itself (C. Shepard, pers. comm) (Table 5). Seacages however, are reported to become heavily fouled with species including bivalves. There is the perception that settling juveniles may find these bivalves a ready food source and settle onto cages, where, due to their small size they are overlooked. Once the food has been consumed, adult seastars drop to the bottom. There is the possibility for translocating marine pests, because seacages are dragged from their lease areas in south-east Tasmania to the Huon Estuary for freshwater exposure, to rid salmon of parasites. A farmer reported seeing the fouling Japanese "Wakame" kelp (*Undaria)* being transported on salmon cages in Tasmania. However, the same farmer reported that salmon sea cages are now "heavily anti-fouled to keep seals out" and that this may reduce bivalve numbers and hence seastars from entraining onto salmon cages.

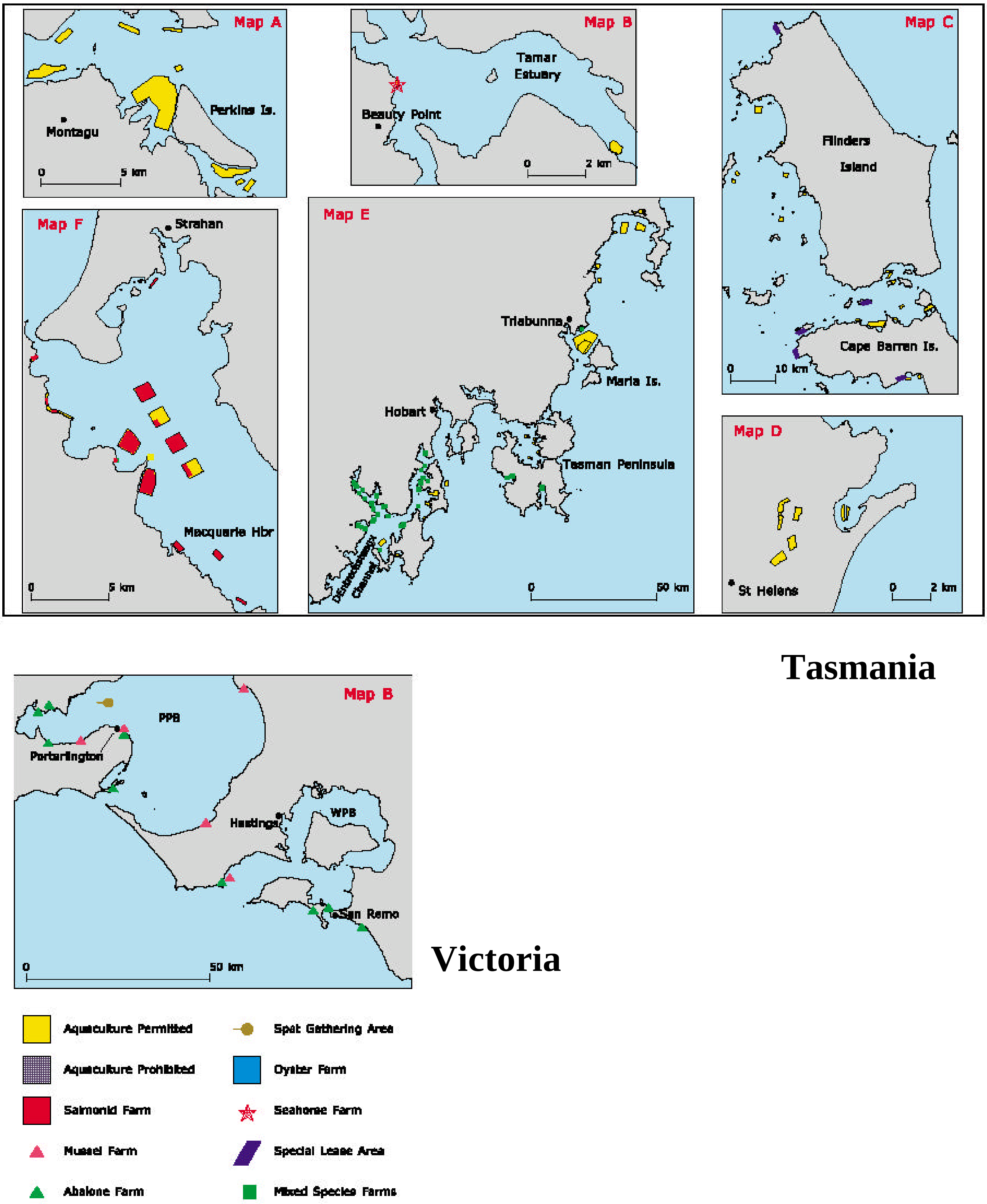


Figure 2 – Aquaculture activities in Tasmania and Victoria from Larcombe et al. (2002)

Table 5 - Phone surveys [1] of aquaculture operators

Culture	n	Location	Have you lost any stock to predation by seastars (North Pacific or native seastars)?	Have you ever seen any seastars (North Pacific or native seastars) on your gear or in your stock?	Comment
Abalone	4	Respondent 1 , Western Port Bay	No	No	Offshore facilities
		Respondent 2, Western Port Bay	No	No	Onshore facilities
		Bicheno, Tasmania	No	No	Onshore facilities, Outside of infection sites
		Dunalley, Tasmania	Yes	Yes	Onshore facilities
		Consultant to farms, Tasmania	Yes	Yes	Offshore facilities, only native seastar
Mussels	2	Port Phillip Bay, Victoria	Yes	Yes	
		Deep Bay, Cygnet, Tasmania	Yes	Yes	
Oysters	7	Little Swanport, Tasmania	No	No	Outside of *Asterias* infection sites
		Pipe Clay Lagoon, Tasmania	Yes	Yes	Inside *Asterias* infection site
		Great Bay, West Bruny Island, Tasmania	No	No	Outside of *Asterias* infection sites
		Bruny Island, Tasmania	Yes	Yes	Only predation by native (11-arms) seastars
		Norfolk Bay, Tasmania	No	No	No stock loss by any seastar
		Great Bay, D'Entrecasteaux Channel	Yes	Yes	Loss to both native and introduced seastars
		Cloud Bay, Bruny Island	Yes	Yes	Only predation by native (11-arms) seastars
Salmon	3	D' Entrecastreux Channel	No	No	
		South East Tasmania	-	-	
		South East Tasmania	No	No	
Scallops	2	Mercury Passage, Tasmania	Yes	Yes	
		D' Entrecastreux Channel	Yes	Yes	
Spat	1	Shellfish culture, multiple sites	No	No	Onshore facilities

1 – Interviews of licensed operators and or facility managers by Michaela Dommisse in 2003

- ***Mussels***

Victorian mussels supply around 40% of Australia's mussel production and this is expected to increase. Most mussels (*Mytilis edulis*) farming in Victoria occurs in Port Phillip Bay and Westernport Bay (J. Mercer, pers. comm.). In Tasmania there are farms on the east-coast – although all of these are mixed species farms. Mussels are collected as wild spat from collectors hung on long-lines, or more recently reared in hatcheries. In Tasmania most collection of mussel spat occurs in the Frederick Henry Bay area (DPIWE cited in Martin and Proctor (2000)), while in Port Phillip Bay, spat is collected from a 0.25-0.50 km^2 area off Werribee. Mussels are then grown out on long lines taking 15 months to two years to reach marketable size (National Oceans Office, 2002). Once this occurs, mussels are shipped live to the main markets of Sydney and Melbourne (National Oceans Office, 2002)

Asterias have been observed predating on spat on collecting ropes and sometimes on grow-out ropes if these fall to the bottom (Table 5) (J. Mercer, G. Parry, pers. comm). In 2004, a large recruitment of juvenile seastars has been observed in an experimental shellfish lease site in Pinnace Channel, southern Port Phillip Bay (Fig. 3). Native 11-arms seastars adults, more commonly found climbing the mussel ropes than *Asterias* in Port Phillip Bay, but this is only when ropes are poorly managed and touch the bottom (L Wiffen, pers. comm.). Despite this, seastar predation is not considered a big threat to stock losses of mussels. This is possibly because in Port Phillip Bay, spat are "resocked" and immersed in freshwater before ongrowing that effectively remove seastars and other predators (Gunthorpe et al. 2001). In Tasmania, such cleaning is not practised but those farmers interviewed in this study did not consider stock losses to the seastar as significant. The only significant mussel stock and gear movement in Victoria is between Port Phillip Bay to Westernport Bay for grow-out phases in production but mussel ropes are cleaned by freshwater immersion before transport, and are therefore not considered a high risk for marine pest translocation. There are no significant mussel stock or gear movements in Tasmania. As most movements are highly localised, or low risk due to cleaning, mussel stock and gear movements are not considered a significant vector for entraining *Asterias* at this stage.

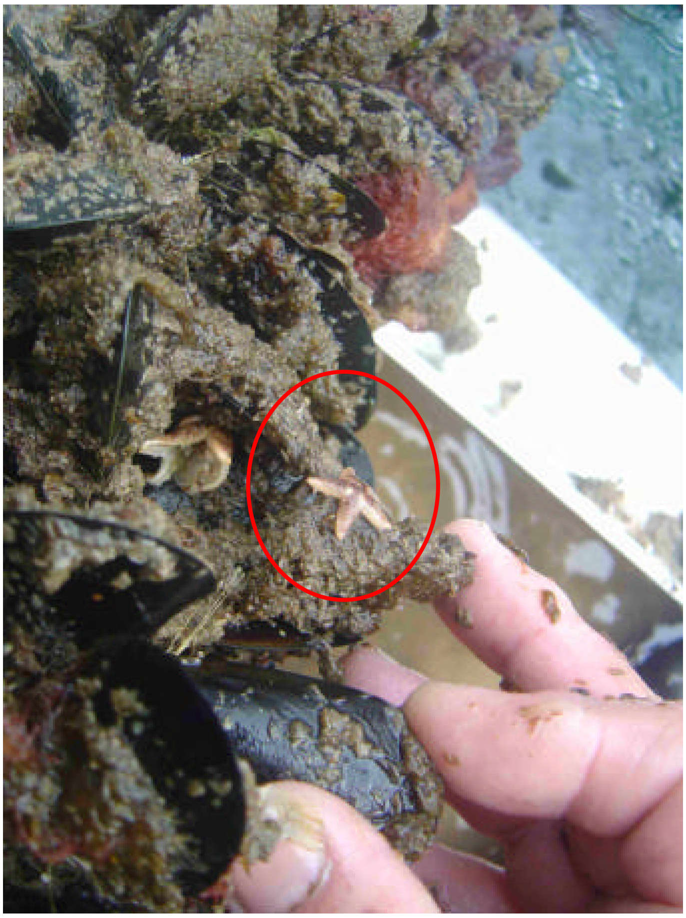


Figure 3 – Recruitment of *Asterias* larvae (shown here as juveniles) on mussel ropes deployed at Pinnace channel, southern Port Phillip Bay

- ***Scallops***

Tasmanian farmers culture scallops in a small number of 'special lease areas' that have been granted for the experimental culture (Larcombe et al 2002). A small number of experimental leases have also been granted in Port Phillip Bay. Scallop spat has traditionally been collected from the wild via mesh bags hung on long-lines. More recently there has been success in rearing them in hatcheries. Spat are hung in cages on long lines and take 4 years to mature (National Oceans Office, 2002). "Ongrowing" is mainly carried out in lantern cages on long-lines (National Oceans Office, 2002).

Asterias are reported settling onto scallop grow out ropes in Tasmania between October and December (Table 5). One farmer reported that settling *Asterias* seastar larvae rapidly grow into juveniles and predate on 100% of stock. Sometimes adults (10cm) have been caught inside lantern cages and may have been there for 8-20months living inside the scallop shell (P. Lamb, pers. comm.). Farmers try to minimise the impact of *Asterias* by timing stock retrieval (late summer/autumn) before peak seastar settlement and rehoused stock through the growing stage, manually sorting them to remove native and *Asterias* before returning stock to the marine environment (P Lamb, pers. comm.). There are no significant scallop stock or gear movements in Tasmania at present, and therefore this is not considered a significant vector for marine pests. However, given that juveniles are reported to "hide" in scallop shells until they reach 10cm in size, a significant potential for translocation exists if the industry, which is still small, expands.

In Port Phillip Bay, a large recruitment of *Asterias* larvae has been observed on scallop nets in an experimental lease site in southern Port Phillip Bay in summer of 2004 (Fig. 4, J. Mercer pers. comm.). While the recruitment is evidence of the ability to entrain on scallop farming gear, the industry is still in its experimental phase in Port Phillip Bay so the potential for translocation of seastars with scallop farming gear is currently limited.

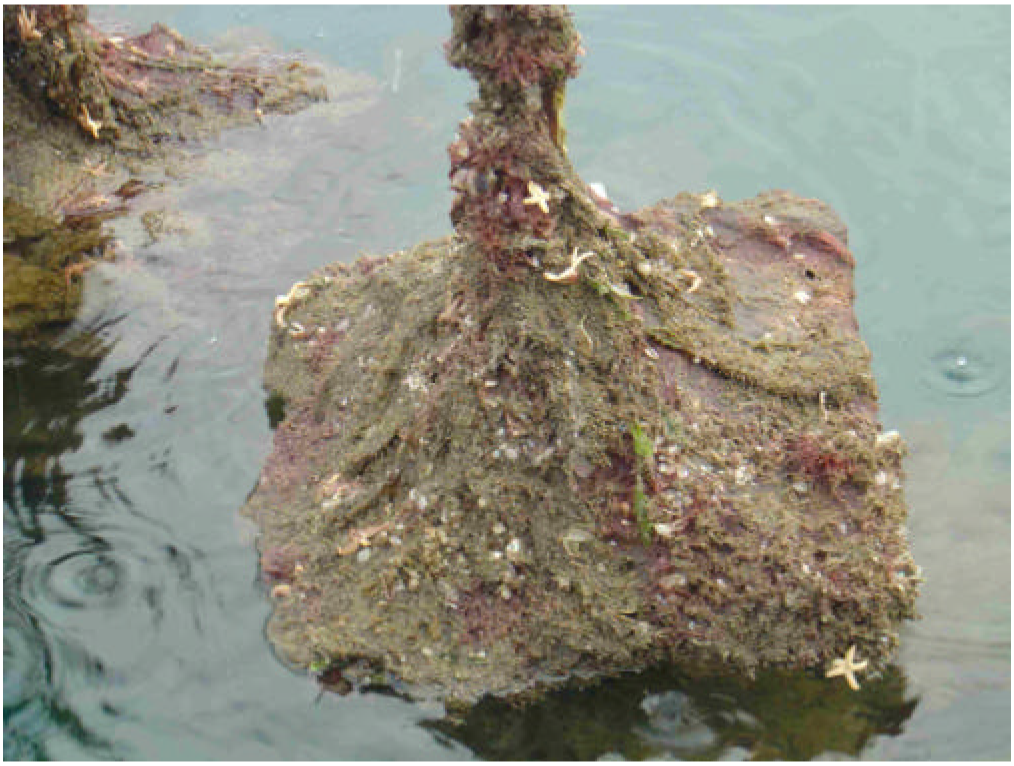


Figure 4 – Recruitment of *Asterias* larvae (shown here as juveniles) onto scallop nets in southern Port Phillip Bay

- ***Abalone***

Abalone farming has occurred recently in Victoria. Several hatcheries and farms are located around Port Phillip Bay and Westernport Bay (mostly at San Remo) as well as west of Port Fairy and Portland. In Tasmania small-scale abalone farming takes place on a handful of tiny leases on Flinders and Cape Barren islands (Larcombe et al. 2002). Abalone spat are produced in hatcheries. In Tasmania hatchery production of both greenlip abalone (*Haliotis laevigata*) and blacklip abalone (*H. rubra*) is well established. Spat are mostly grown out on land based runways or in barrels/cages suspended in the sea where they take between 3 – 4 years to reach market size (Fisheries Victoria, 2001). Abalone farmed in onshore facilities are fed by a continuos exchange system with external waters or by specially cultivated, axenic algae cultures. Marine farms house abalone in smaller cages within larger cages secured to the seafloor.

There is the perception from farmers interviewed in this study that both land–based and marine abalone farming is not impacted by *Asterias* or other seastars because farming is very visible and contact frequent (S Rodisz, pers. comm). Tanks are cleaned and/or drained daily to remove faeces buildup and reduce bacterial growth. *Asterias* would be visible and removed before they became large enough to predate on abalone. Despite this, one abalone farmer reported that an adult *Asterias* has been observed in a tank in an onshore facility in Tasmania. Although there are screens, the perception of this farmer is that adult seastars appear to be able to crawl up the water intake pipes to tanks and grow large enough to spawn. Biscuit stars have also been observed in onshore abalone tanks. No predation of abalone has been recorded, but this could be because seastars entering tanks as larvae are removed before they grow to feeding size. An aquaculture consultant in Tasmania noted one occasion, where an 11-arm native seastar was found in the abalone seacages of an offshore farm (D. O' Brein, pers. comm). There are no large abalone stock or gear movements in Tasmania or Victoria at present, and therefore this is not currently considered a significant vector for *Asterias*.

- ***Oysters***

There is a small production of native flat oysters (*Ostrea angasi*) in Tasmania but the main production comes from the Pacific oysters (*Crassostrea gigas*). Farms are located across the whole East Coast of Tasmania. A number of specialised hatcheries around the east-coast produce the spat, which are on grown in baskets ("lanterns") hanging on intertidal or sub-tidal rack systems. The oysters reach market size ~2-3 years (Aquaculture Research Advisory Group, 1999). The majority of Pacific oysters are sold live into the Australian market with Victoria purchasing the most, although Queensland and Sydney are beginning to take more.

There was a mixed response on the impact of seastars on oyster culture from farmers interviewed in this study, with leaseholders in areas most densely populated with *Asterias* the most affected. In these areas, *Asterias* are reported to climb up the intertidal oyster rack and predate on the stock by extension of their tube feet or by climbing directly into the baskets. The perception has been that the intertidal environment is too dynamic for seastars (C Dyke, pers. comm.), particularly on the retreating tide, but seastars are reported to shelter in "rock channels" to avoid air exposure and water movement. The native 11-arm seastar was also reported to predate heavily on stock, up to three times as much as *Asterias* at a particular farm and is commonly reported to predate on adult stock at other farms (see Table 3). Most stock loss is due to adult predation after climbing onto racks. There is no loss of spat to seastar predation because they are grown in encapsulated trays. Farmers practise some management of the seastar by removal and disposal on land.

From many conversations CSIRO has had with farmers over the years, it appears that the processes (submerging in freshwater and alike) that are intended to rid seed oysters of other marine life prior to shipment to other regions (both within Tasmania and interstate) are not effective (C. Proctor, pers. comm). This is corroborated by two Tasmanian farmers in the survey reporting finding a small crab in the spat bought from a specialised oyster culture company. At present, there is some movement of oyster stock and gear in Tasmania, but this is mainly from areas uninfected by the seastars to infected areas (North to South) (A. Morris, pers. comm.). There is a great potential for intrastate translocation of pests by oyster spat because treatment requirements are not currently systematically applied. (eg freshwater immersion). However, this will change with the uptake of the *National Policy for the Translocation of Live Aquatic Organisms* (Ministerial Council on Forestry, Fisheries and Aquaculture 1999).

Conclusions

In summary, marine-based aquaculture may be considered a high-risk vector for potentially entraining *Asterias* because of the propensity for seastars to congregate at farms. However, not all aquaculture operations are impacted. Oyster and scallop farming in Tasmania appears to be most impacted by *Asterias* predation. While there are no significant stock and gear movements of scallops in Tasmania, until stock go to market, this is not the case for oysters. Oyster spat has been implicated in the spread of organisms both intra-state and inter-state.

While aquaculture, other than oyster spat, appears to not represent a significant risk for pest translocation because stock and gear movements are localised, consideration should be given to implications of a rapid expansion of the industry. Production estimates in 1998/99 reached $610 million, with 80% of production coming from five main species: pearls, oysters, salmon, prawns and tuna. In the last three years aquaculture production has increased by over 40%. Industry has forecasted that by 2010 (Victoria 2001), the aquaculture industry in Australia will achieve annual sales of $2.5 billion, a *four-fold* increase on current production (National Oceans Office, 2002). The increase in productivity may represent a commensurate increase in the risk that aquaculture gear and stock can spread marine pests. Management is tractable since 1) effective and efficient risk abatement options are available in most instances and 2) mandatory licensing for marine farming includes conditions to ensure that farm operations have a minimal impact on the marine environment. Moreover, the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* increases the scrutiny that new developments such as marine aquaculture operations will undergo if they are proposed to be located in sensitive environments (Larcombe et al. 2002). Regulation to reduce the risk of entraining and translocating *Asterias* by this vector group exists and should translate into practical application (better cleaning and screening) with the uptake of the *National Policy for the Translocation of Live Aquatic Organisms* (Ministerial Council on Forestry, Fisheries and Aquaculture 1999).

FISHING GEAR

The National Introduced Marine Pest Information System (NIMPIS) reports "swarms of seastars" damaging trawl and gill nets of Japanese fisherman and destroying their bait or the catch of setline and hooks (NIMPIS, 2002). Likewise in the Gulf of Alaska, trawl fisherman have reported significant damage to their nets by large amounts of *Asterias* bycatch following the collapse of the King Crab population (D. Urban, pers. comm.). *Asterias* was also a significant component of bycatch in an experimental trawl study in the Bering Sea (Brown et al., *accepted*). In Australia, the propensity for benthic fishing gear to entrain *Asterias* is also evident in the initial incursion of the seastar to Port Phillip Bay. Although there were extensive searches by divers, the first two specimens of *Asterias* were both found by scallop fishers who had been dredging the area extensively (Garnham in Goggin (1998)). *Asterias* have been reported entrained by scallop fishers in Mercury Passage and off Huon Island (Morrice 1995). These reports corroborate expert opinion that fishing gear has a high probability for entraining *Asterias* and potentially spreading it to new locations within Australia (Dommisse and Hough (eds) 2002)

For this study, phone interviews and web surveys were used to obtain information on *Asterias* entrainment by fishing gear (commercial and recreational) in Port Phillip Bay and southeast Tasmania. Personal communications are listed in Appendix A.

Commercial fishing

In Tasmania, the commercial fisherman's peak body, the Tasmanian Aquaculture and Commercial Fishing Council had not received any reports that inshore commercial fishers (gill nets, drop-lines, hand-lines) had entrained *Asterias* (B Lister, pers. comm.). The perception was that although entrainment may occur, it was not frequent and therefore not brought to the Councils attention. This may also be partly due to the ban of hook and net commercial fishing in the Derwent River, where the main population of *Asterias* resides.

There has been an anecdotal association between the establishment of *Asterias* in Henderson's lagoon, southeast Tasmania and the live fish trade (Proctor and McManus 2001). The perception from local residents is that the only way *Asterias* could get into the lagoon was by the live fish trade, as the lagoon is largely isolated from the adjacent sea. It is believed that a vendor left *Asterias* contaminated live fish cages in the lagoon while enroute to northern Tasmania. However, no direct observations of this entrainment have ever been made (N. Bax, R. Thresher, pers. comm.).

Unlike the Derwent Estuary, hook and net commercial fishing is still practised in Port Phillip Bay (Fisheries Co-management Council, 1997). Scallop dredging, reported to entrain huge quantities of seastars, has been banned in the Port Phillip Bay since 1997 (M. MacDonald pers. comm.). The main commercial fishing methods used are purse seines, haul seines, long lines and mesh nets, with more than half the commercial catch caught in haul seines (Fisheries Co-management Council, 1997). Purse seiners target small pelagic fish such as anchovies. The bottom of the net is closed to form a "purse" around fish and is suspended from the bottom with floats. The net doesnot touch the bottom, and as such it is not expected that *Asterias* are easily entrained. Not surprisingly, no commercial fisherman operating in Port Phillip Bay using purse seines have reported encounters with seastars (M. MacDonald, pers. comm). Fisherman targeting scalefish using meshnets have reported the occasional *Asterias* clinging to the nets as they are brought in after overnight deployment (M. MacDonald pers. comm.). In between deployments nets are air-dried for at least 6 hours, which may reduce the risk of translocation of seastars on the next deployment.

Haul seining is the largest fishery operating in Port Phillip Bay (Fisheries Co-management Council 1997). Haul seine nets also touch the bottom and therefore have a risk of entraining seastars that cling to nets (M. MacDonald pers. comm.). A haul seine fisherman reported catching *Asterias* ~1-2 times per year in his nets, but all his fishing was in the southern part of Port Phillip Bay where the *Asterias* population is currently low (Parry et al. 2003). He reported catching the native 11-arms seastar on a regular basis (~1-2 per haul) indicating that seastar entrainment at higher densities is very likely. Currently, most haul seining in practised in the shallow western side of Port Phillip Bay (Fisheries Co-management Council 1997), where *Asterias* abundance is low (Parry et al. 2003). Entrainment of Asterias into haul seines is therefore also expected to be low unless the industry extends its range into areas of high Asterias density or the pest in turn, has a significant range extension into haul seine fishing grounds.

By far, the most frequent entrainment of *Asterias* onto commercial fishing gear is reported from long-line fishers (M. MacDonald, J. Newman, pers. comm.). These fishers report significant problems getting bait to their target fish (snapper and gummy shark in Port Phillip Bay), because of *Asterias*. One fisher reported that almost all his hooks (up to a maximum of 200 hooks) caught *Asterias* in areas of high infestation in Port Phillip Bay. On pulling up the line, the majority of seastars dropped off. It is unclear if frequent entrainment on longlines is because it is mechanistically more likely than other fishing gear (eg haul seining) or because, most long lining is practised in the deeper water of Port Phillip Bay where *Asterias* densities are highest (Parry et al. 2003). All commercial fishers interviewed in this survey were familiar with *Asterias*. When entrained, fishers disposed of seastars by air-drying them and placing them in a land-based disposable facility.

The most prevalent live fish trade is for wrasse. Most of the fishing is done off the central west-coast of Victoria, but some wrasses are collected at the entrance to Port Phillip Bay, where there is a possibility that *Asterias* may be entrained. Wrasses are caught by hooking (2 hook line), then are kept in live wells on the boat and sent to Melbourne or Sydney. None of the wrasse fishers operating outside Port Phillip Bay had ever caught *Asterias*, although they all knew what it was. However, one did report catching the native seastars at a low frequency (~1 per year), so it seems the mechanism for entrainment does exist. A smaller, developing fishery (2 licenses at ~50fish day^{-1}) is for banded morwong, which takes 10 tonne per annum and compares with the larger wrasse fishery which takes 40 tonne per annum. Banded morwong are caught with meshnets to the east of Lakes Entrance, which is outside of the current range of *Asterias*.

Recreational fishing

Recreational fishers were asked to relate their experiences with *Asterias* through a web survey or contributing to a reader's forum on "Fishnet" (http://www.fishnet.com.au/forums/). The latter responses did not provide additional insight into entrainment of *Asterias* by fishing gear other than it had occurred (Appendix C). The head of the largest recreational fisheries group in Tasmania (D. Patton, pers. comm) had no reports of *Asterias* entrainment by recreational fishing gear. It was his opinion that club members perceived seals as a much more significant "marine pest" than seastars, which were not considered a hindrance to fishing by recreational anglers.

To obtain more information on the interactions between seastars and recreational fishers a request for completion of the web survey (www.nre.vic.gov.au/coasts/survey) was posted to Victorian fishing clubs and other boating groups. There were ~240 responses to a web survey over a 12-month period (Jan 03 – Feb 04). The primary activity of respondents was recreational fishing (39%), followed by recreational boating (26%) and sailing (17%). The most common type of vessel (40%), used was a small motor/speedboat, (<7m =50%) cruising yachts (23%) and trailer sailer (18%). A large proportion of these vessels were stored outside of the water in a marina (24%) or on a mooring (19%). Only 22% of respondents, mostly recreational fishers, were familiar with *Asterias*. In June 2003, a question was added to determine if respondents could correctly identify *Asterias* from four other seastar species. Twenty-nine respondents attempted the identification with the majority getting it right (21). Of the incorrect selections (8), half were for the common eleven-arm native (*Costanasterias* *muricata*); one was for the five-arm zigzag seastar (*Uniophora sp*), one for a biscuit seastar (*Patriella sp*) and two for *Nectria sp.*. Three of the respondents that misidentified *Asterias* were quite confident that they were correct, while the remaining five were not confident. Most of the respondents that correctly identified *Asterias*, were confident that they were correct (>80%). Due to technical difficulties, respondent's details of *Asterias* entrainment were not recorded until late in the survey. As a result, only 6 respondents indicated where they had entrained the seastar during boating activities. Most of these reports were for *Asterias* caught by baited hook (4), but other incidents observed include –a seastar brought up with the anchor and a seastar observed in the burly bucket. One respondent had only seen them on wharves and artificial structures. It is notable that commercial long-liners also report most catches of *Asterias* on baited hooks. Most recreational respondents that recognised the seastar only saw it very occasionally (2-3 times per year), suggesting that interactions, and hence entrainment was not very frequent by individuals in this vector group.

Conclusions

The encounters that haul seine and hook and bait commercial and recreational fishers report with *Asterias* in Port Phillip Bay suggests that fishing gear can certainly entrain *Asterias* and therefore has the potential to be a major vector for translocating *Asterias*. Mesh-netting and live fish fishing may also become significant if the seastar extends its current range and density in Port Phillip Bay to include additional areas where this fishing is currently practised. However, as evidenced from the interviews and web survey for this study, Port Phillip Bay fishers (commercial and recreational) are aware of *Asterias* and its potential impacts and are likely to remove and dispose seastars if spotted in their gear. While this reduces the translocation of visible adults, it is currently not known whether larvae may settle onto fishing gear and be translocated as tiny individuals (mm size). To mitigate such spread and reinforce prevention options a brochure has been produced that details the steps required to keep boats and gear clean of marine pests (Appendix D). The application of the guidelines in the brochure is critical to prevent the further spread of *Asterias*, and other pests, given the growing recreational fishing sector. Application is encouraged because of a shared stewardship for the marine environment. The Seafood Industry, in partnership with Seanet intends to introduce the practical steps required to keep boats and gear clean from marine pests in their national seafood-training package for commercial fisherman (J. Newman, pers. comm.).

VESSEL HULLS

Fouling of hulls, 'nooks and crannies' and intakes pipes of hulls has been a major vector for translocating marine and aquatic pests across the world's oceans and waterways (Carlton 2001). While the potential ecological impacts of such translocation are recognised (Carlton and Geller 1993), hull fouling also represents a major cost to the owners of ocean-going vessels because of reduced fuel efficiency and ongoing costs of maintenance (Floerl and Inglis 2003). For a 50,000 DWT tanker, it has been estimated that hull fouling could reduce ships speeds by ~2 knots resulting in a 39% increase in fuel consumption (Walters 1997).

Recent improvements in antifouling paints, increasing vessel speeds, and more frequent dry dockings are believed to have significantly reduced the successful transport of pests, however hull fouling is still implicated as a major vector for translocating marine pests (Hewitt et al. 1999). In Australia, this was highlighted by the outbreak of the black striped mussel in 1999 in Darwin Harbour (Bax 1999). The Black Striped Mussel belongs to the same family as the Northern Hemisphere's zebra mussel (*Dreissena polymorpha*), which has been responsible for costly damage to infrastructure in the Great Lakes. It is believed to have arrived on the hull of an ocean going vessel and was spread to local marinas by other yachts. A successful eradication, at a cost of ~$3million, was undertaken because of the mussels threat to the local biodiversity, recreation and commercial industries (Ferguson 2000).

Hull fouling is suspected to be a primary vector for translocating *Asterias* (Hewitt et al. 1999) particularly after an adult was found in the sea chest of an ocean going vessel (Thresher et al. 2000). However, it is not known how frequent translocations may be on vessel hulls and associated areas. The aim of this study was to assess the strength of hull fouling as a vector for spreading *Asterias*. A literature review of hull fouling studies has been conducted to assess the frequency of vessel hulls entraining seastars. In addition, industry personnel involved in hull maintenance have been interviewed for their anecdotal observations of seastars (if any) being entrained onto hulls and associated areas as an indication of the likelihood that the vector would spread *Asterias*.

Seastars and hull fouling

Hull fouling has been the subject of an extensive review recently conducted for the Australian Government (AMOG 2001). Of the 1000 or so studies reviewed, none reported finding seastars or other echinoderms on hulls. Only the common brittlestar, *Ophiactis savignyi*, is occasionally known to inhabit fouling communities on boats and other artificial oceanic structures (Roy and Sponer 2002). This low incidence of entrainment rate of seastars onto hull corroborates with (AQIS 1994) that "it is unlikely that starfish would remain attached to vessels for any length of time and this is not perceived to be a significant means of translocation".

However, mobile organisms such as *Hemigrapsus penicillatus* have been found in empty barnacle shells in the hull fouling community (Gollasch 2002). Thus mobile organisms, such as *Asterias* may be sheltered for weeks or months among the fouling assemblages or in other sheltered regions of the hull. Sea chests are known to be particularly amenable to accumulations of organisms that would not survive on the hull of the ship, and these are now increasingly suspected of playing a significant role in introductions (Carlton 2001). Indeed there has been one report of an adult *Asterias* observed in the seachest of a commercial vessel operating between the Derwent Estuary and Port Phillip Bay (Thresher, pers. comm). In Tasmania there was an incident involving a small *Asterias* (5cm) in Burnie, found on the mooring lines of a merchant vessel as they were being uncoiled on deck (15/10/02) (A Morris, pers. comm). AQIS inspectors also found a desiccated *Asterias* on board a vessel ~6 years ago that was sourced from Japan. However, it is unlikely that these specimens were viable (A Morris, pers. comm).

None of the slipway operators surveyed in this study recorded seeing *Asterias* on the hull of a vessel although one operator did observe a seastar on the cradle used to lift a vessel out of the water (Appendix E). The two scrubbers surveyed did not observe adult seastars on any of the hulls of the boats they had cleaned since 1995. One scrubber reported seeing *Asterias* just below the waterline on the marlin board of a catamaran. The other scrubber reported seeing hundreds of tiny "seastar like looking things" in the water column around the hull of the boat he was cleaning around the time when some *Asterias* larvae settlement is expected (October). Until these are collected and identified, however, little can be said about the potential for juveniles to settle onto boat hulls from the water column. Four experts researching fouling in the Derwent Estuary and Port Phillip Bay were also contacted but none of these recorded seeing *Asterias* on a hull, seachests or any of the plates they set out to investigate fouling communities (see Appendix F).

Conclusions

While it does appear possible that adult *Asterias* could entrain in the sheltered areas of a hull or its nooks and crannies like the seachest, the paucity of direct observations suggests it is a rare occurrence. However, one possibility that should not be ruled out is that juveniles settle out of the water column or are entrained onto the mooring ropes and hulls, including seachests of vessels. There is also the perception that *Asterias* has not been found on hulls because no one is looking for them (M.

Keough, pers. comm). This is particularly the case for very small individuals that may not be readily visible in seachests or are destroyed during cleaning (T. Dodghsun, pers. comm). If juveniles can settle and remain on hulls then fouling may not be such an insignificant vector for transporting *Asterias* as this study suggests. In 2003/2004, CSIRO plans to conduct a study that uses gene probes to identify *Asterias* on boat hulls and associated nooks and crannies (K. Hayes, pers. comm). This research will further help resolve the risk of boat hulls for translocating juvenile *Asterias*.

4. IDENTIFICATION AND ASSESSMENT OF PRACTICAL OPTIONS FOR BETTER EARLY WARNING SYSTEMS TO DETECT ASTERIAS AND OTHER EXOTIC SPECIES INTRODUCTIONS

INTRODUCTION

The original aim of this project was to identify effective and efficient practical options for providing earliest possible detection of *Asterias* introductions at new locations. Early detection of a pest species offers the best chance at eradication, albeit usually under extremely fortuitous circumstances. More realistically, early detection offers the best chance for control of the population and stopping its spread beyond an area of infection.

During the development of this project (October 2003), the Natural Resource Management Ministerial Council endorsed the following "a species targeted national program of in-port pest monitoring be established within one year to support the prevention and emergency preparedness elements of the National System”. The focus of the Port Monitoring Program is to be based on the probability of introduction for a given location and the feasibility of detecting pest introductions to inform risk or emergency management assessments. This program should be developed by NIMPCG. The port monitoring program is to be explicitly developed for early detection of marine pests, including *Asterias* and/or to routinely update risk based assessments to enable point to point risk assessments. National guidelines are to be developed that consider the early detection of *Asterias* and other pests far more comprehensively than within the scope of this project. To avoid a duplication of effort, it was agreed that this project would be considered as part of the greater national guidelines for port monitoring. Given the port monitoring program is currently being developed and is not expected to be complete until year-end 2004, this report details initial progress with the framework for a targeted port monitoring program.

Development of the National guidelines

In 2003, a working group was established to develop the national guidelines for in-port monitoring of target pest species at high-risk ports. The working group consists of Simon Barry (BRS), Nic Bax (CSIRO) Michaela Dommisse (Vic-DSE), Piers Dunstan (CSIRO), Keith Hayes (CSIRO), Don Hough (Vic-DSE) and Sasha Migus (CSIRO).

Collaboration between members has led to a framework for design of a standard monitoring protocol in Australian ports, which has been endorsed by the National Introduced Marine Pest Co-ordination

Group (NIMPCG9). It has been agreed that the aim of the monitoring is to inform national decisions with regards prevention and emergency preparedness, specifically:

1) Provide for the routinely updating risks associated with the movement of vessels between international and Australian locations and between Australian locations (eg ships carrying ballast water)
2) Provide for the early detection of target species introductions to prevent their further translocation

The working group is currently devising the most optimal survey design to achieve these goals, that takes into consideration: the selection of target species, the selection of an acceptable detection threshold for target species; the selection of sampling locations for monitoring, the selection of best practise techniques for sampling target species, and cost (in absolute terms and relative to other risk abatement strategies). Thus providing a basis of longer-term policy decisions on the best resource allocation to manage marine pests.

Selection of target species

Species on the next pest list are considered, on the basis of evidence to date, to pose the greatest risk Australia and are obvious candidates for monitoring (Hayes and Sliwa, 2003). However, for design purposes it is more practical to group pests into functional groups to avoid redundancy in their monitoring. For example, multiple target species with a planktonic life-stage can be monitored using plankton net trawls. To maximise the return on monitoring, target species on the next pest list are therefore considered in terms of the following functional groups:

1. sessile species that foul on hard substrates;
2. sessile species that foul on soft substrates;
3. species with a planktonic life-stage (either tychoplanktonic; meroplanktonic; holoplanktonic);
4. species with motile life stages on hard substrates;
5. species with motile life stages on soft substrates.

Selection of a detection threshold for target species

The detection threshold for target species depends on its purpose: is the intention to eradicate a new established population or to adaptively respond to its presence? ‘Eradication monitoring’ requires the early detection of very low numbers of a pest population still in its lag phase and hence in a highly localised area. Studies have shown that when a pest founding population is rare, early detection of individuals will involve considerable sampling effort that is likely to also have a high failure of detection (Type II error). Once detected, the general view held in invasive species research is that while success will depend on the pest species (those with a pelagic larval stage disperse very quickly) and the unique features of the incursion (eradication is more probable in hydrodynamically isolated environments such as lochs) eradication is typically impossible. Given this, the implication is that the monitoring resolution required (with regard to space, time and certainty), and its associated cost is likely to exceed the capacity to achieve the management goal (eradication), and therefore does not represent a return on investment.

In contrast, monitoring in order to adaptively respond and manage the population by, for example, controlling its spread does not require detection at the low densities required for eradication. It is anticipated that this will lower the sampling effort and cost. In this context, monitoring to manage pests is at cost scale that is relevant to the capacity to respond and therefore represents a potential return on investment. Consequently, monitoring to manage marine pests represents a minimum national effort. These arguments briefly explained above are extensively developed by Barry (2004).

For the guidelines, management monitoring is aimed at preventing the further spread of marine pests by informing point to point risk assessments in the BWDSS. For these purposes, the pest population does not have to be found, only detected. If undetected, then the probability of the pest being translocated is assumed to be commensurately small for the purposes of the BWDSS. If detected above a threshold, then the risk of translocation is considered significant, regardless of the population size or location.

An approach to selecting the detection threshold that is consistent with current practice, is to use the risk threshold applied to vessels undertaking ballast water exchange enroute from international locations. Exchange is achieved by either emptying ballast tanks and then refilling them with oceanic water (empty/refill) or running ballast pumps to allow three times the volume of the tanks to flow through the open inspection hatch and over the ships side (flow through). Treatments result in at least 95% of the original ballast being replaced with oceanic waters, with the assumption that this reduces the initial particle (organisms) concentrations by 95%. Thus, ballast water containing 5% of the original population density is considered acceptable for discharge into Australian ports.

On this basis a pragmatic detection benchmark for a newly established population is 5% of the typical density of an established population. At a 5% level, populations are detectable with quite limited sampling (with relevant species, gene probes would make this a trivial exercise), and this can be done rapidly and cost-effectively. The working group has agreed that 5% of maximum densities for example-species from each functional group would serve as the detection thresholds for the port monitoring guidelines (Table 5). It was also noted, that the detection threshold can be modified as experience is gained.

Table 6– Threshold densities at 5% of the recorded maximum density for example species in functional groups.

Species Name	Sessile Fouling (Hard)	Sessile Infauna (Soft)	Mero-planktonic	Holo-planktonic	Motile (soft)	Motile (hard)
	No/m^2	No/m^2	No/m^3	No/L	No/trap/night	No/trap/night
Alexandrium minutum		800		50000		
Asterias amurensis	0.05	0.05	38.5			
Corbula gibba		4.35				
Crassostrea gigas	0.25	0.25				
Gymnodinium catenatum		8.825		31300		
Mnemiopsis leidyi						
Potamocorbula amurensis		160	7.9			
Sabella spallanzanii	50	15				
Undaria pinnatifida	7	7				
Carcinus maenas			0.3		1.955	1.955
Musculista senhousia	147.5	147.5				

Selection of monitoring locations

It is not practical to census the entire Australian coastline. Consequently, criteria must be identified that allow nodes to be identified: first in terms of the likely hood that a pest will be introduced to these locations from an overseas source, and second that they will act a source from which they can be dispersed within Australia. These locations are most obviously ports and are as follows:

1. Group one - Recipient ports at highest risk from **primary introductions** from overseas traffic and;
2. Group two - Donor ports at highest risk of translocating established marine pests because of their high connectivity to other domestic ports (**secondary invasions**).

To make the best use of existing information, the working group has adopted a pragmatic approach modified from that of Inglis (2002) and used the following variables to rank the importance of ports in terms of monitoring:

- Number of international merchant vessel arrivals (surrogate of hull area)
- Volume of internationally sourced - ballast water discharged received
- Number of international source ports (connectivity),
- Number of international pleasure vessels arrivals
- Number of source ports of international pleasure vessels,
- Number of fishing vessels arriving from an international location.
- The residence time of water in the port

Principal Components Analysis (PCA) was used in an initial analysis of these variables. It was recognised from the PCA analysis that it was critical that the ports be considered in terms of their role in the network of vectors across Australian and this is currently being addressed.

Based on existing survey data, the network analysis is being further supplemented by consideration of:

- The presence or absence of target species within the donor and recipient port
- Whether the port has been surveyed or not (unsurveyed ports are assumed to contain all target pest species suitable to that habitat).
- The length of the journey between ports (< 100 days is high risk)
- Environmental matching between ports (eg. temperate to temperate is high risk).

By this means it will be possible to rank those locations where monitoring data will be most informative in managing a national response to the risk of incursions. The network analysis and subsequent ranking will also provide a context for assessing monitoring that may be required to meet local requirements.

APPENDIX A PERSONAL COMMUNICATIONS

- Mr Peter Yaxley – Oyster farmer, Pipe Clay Lagoon, Tasmania
- Dr Greg Parry – Member, Marine and Freshwater Resources Institute
- Mr John Mercer – Aquaculture liaison officer, Marine and Freshwater Resources Institute
- Mr Lance Wiffen – Mussel farmer, Port Phillip Bay and Westernport Bay
- Mr Colin Dyke – Oyster farmer, Little Swanport, South East Tasmania
- Dr Craig Proctor – Scientist, CSIRO CRIMP
- Mr Phil Lamb – Scallop farmer, Mercury Passage, Tasmania
- Mr Steve Rodiz – Secretary of the Victorian Abalone Growers Association
- Mr Dominic O' Brein – Aquaculture consultant, Tasmania
- Dr Alice Morris – Senior Marine Environmental Management Officer, Department of Primary Industries, Water and the Environment, Tasmania
- Mr Colin Shepard – Manager Marine Environment, Department of Primary Industries, Water and the Environment, Tasmania
- Mr Dan Urban - Fisheries Wildlife Officer, Alaska Department of Fish and Game, Alaska, USA.
- Mr Bob Lister – Director, Tasmanian Aquaculture and Commercial Fishing Council
- Mr Don Patton – Chair of the largest Tasmanian recreational fisherman's group
- Dr Nic Bax – head of CRIMP CSIRO
- Dr Ron Thresher – ex-head of CRIMP CSIRO and current member of CRIMP CSIRO
- Mr Tim Dodgshun - Marine Biosecurity Research Group, Cawthron Institute, New Zealand
- Assoc. Prof. Mick Keough – Marine Scientist, University of Melbourne, Australia
- Dr Keith Hayes - current member of CRIMP CSIRO
- Dr Caroline Sutton - current member of CRIMP CSIRO
- Ms Avril Brown – Recreational divers liaison, Department of Primary Industries, Water and the Environment, Tasmania
- Mr Jim Newman – Seanet representative, Victoria, Seafood Industry Victoria

APPENDIX B QUESTIONAIRE (standard questions for marine farmers interviewed between July 2002 and May 2003)

1. What do you farm? (Tasmania or Victoria)
2. Where is your lease?
3. Do you have more than one lease?
4. Where do you get your spat?
5. Is there much gear movement or stick movement between you leases or elsewhere?
6. Have you lost any stock to predation by seastars (North Pacific or native seastars)?
7. Have you ever seen any seastars on your gear or in your stock?

APPENDIX C FISHNET RESPONSES

The following are key quotes relevant to this paper from the respondents through the FISHNET network.

1. Posted: 07-08-2002 18:43

“I'd much rather have a scallop wrapped around my line than a bloody star on the hook. I haven't seen a scallop since the stars became noticeable’.

2. Posted: 07-08-2002 19:59

‘Seems they are confronted with a mammoth problem but they are working on developing a gene that will keep all the starfish as single gender and hence control the reproductive capabilities. It seems each starfish is capable of carrying up to 3 million eggs and many are released when fish is in danger such as when we catch them on a hook! It would be nice for all at Fishnet to show a posting here to confirm our support for their work!

“You will find that the professional long liners have mainly worked the lower reaches of Port Phillip Bay over the last few years as they can have an entire shot eaten out by starfish in the north. It is not uncommon for a half to a full fishbox of starfish per shot (200 hooks!). I doubt that any recreational fisherman in Port Phillip Bay has not encountered multiple captures of these vermin whilst snapper fishing over the last few years. How many reports do you want? NB 880,000 holders of Recreational Fishing Licences and that does not include those on pensions, senior citizens, juniors etc”.

3. Posted: 07-08-2002 21:34

“I am surprised at the numbers of seastar visible from the shoreline in the yarra channel recently around the Westgate. I thought then that the seastar numbers are increasing as I encounter a number of them while fishing for Pinkies during the autumn off Black rock. Totally agree that we need to assist here, as responsible fisherman often consider themselves guardians of the areas they fish and therefore should be appreciative of this action on a "growing" problem.”

4. Posted: 07-08-2002 21:43

“Got my support in whatever way I can. Remember the marine pest day we had a couple of years ago out from Patterson River. It was a ripper with all hands on deck. Haven't heard about anymore?”

“It seems we may be damned if we do and damned if we don't. If we pick up a NPS are we adding to the problem when it freaks out and releases its eggs?? I’ve seen dive boats arrive at Queenscliff boat ramp with a couple of dozen on the self draining deck, Has the run off from wet divers then spread eggs from the dive site out the scuppers and all the way into Swan Bay and every where between? The proliferation around Mud Island last summer was disturbing to say the least and now the VCA want to dig 30 million cubic meters of the south channel and spread it all around the bay thus spreading the NPS as well? Science may be our only hope."

5. Posted: 08-08-2002 09:29

"It's amazing I have not yet seen any around Portarlington St. Leonard's yet. The local long liner brought 1 to show everybody back from over Mornington way last season and that's the only one I've seen. Is this because they haven't reached this far yet or is there some other reason. It really sounds as though things are bad up in the top end of the bay."

6. Posted: 08-08-2002 14:52

"Henry, one of the first NPS found in Port Phillip Bay was a couple of Kms north of the George light.!! In a scallop dredge!! Maybe they have eaten all the scallops and mussels and moved!"

"The Nothern Pacific Sea Star is obviously in plague proportions in Port Phillip Bay and most of its tributaries. I have inspected their distribution from the upper reaches of the Patterson Lakes system, to the bottom of the bay near the heads. Their numbers seem to reduce the further south you go and I can only assume that they do not like the faster running water as much as the gentle currents in the upper reaches."

"Again, great to see some work on this huge threat to our environment, a threat which crosses all political and philosophical borders. Interesting to note that (the NGO's) often considered a threat to professional and recreational fisherfolk, considered the Marine Pest issue to be the number one topic of concern to the marine environment in their 2001 Participants Questionnaire. I am sure I speak for all fisherfolk in offering any assistance necessary to complete your work and hopefully find a way to eradicate this, and other marine vermin."

APPENDIX D GEAR AND BOAT CLEANING BROCHURE

(Colour brochure provided with report)

APPENDIX E SCRUBBERS AND SLIPWAY OPERATORS

1. Respondent 1, commercial scrubber on 24/07/02

- Scrubs ~10-15 boats per day in summer, owned a slip and does plenty of recreational fishing. Been in the marine business for ~20 years.
- While, scrubbing has never seen the seastar (adult) on a hull, but has seen them on the transom/marlin platform of a catamaran (below the water line)
- Has seen them around mooring chains and ropes in the marinas
- Has pulled around 2-4 per day on 2 – hook lines while snapper fishing in Port Phillip Bay
- Sabella fouling after 1-year submergence is very bad.

2. Respondent 2, commercial scrubber (30/07/02)

- Scrubs 10-15 boats per week in summer. Dives in Hobson's bay, Up the Yarra River and St Kilda
- While, scrubbing has never seen the seastar (adult) on a hull, but has seen a number of seastar like critters around the hull of the boat he was cleaning close to *Asterias* settlement time. Critters were < 1 cent coin and had five arms. Has seen crabs on hulls though and lots of Sabella (very bad).
- Requested that he collect these "critters" for identification. Note *Asterias* settle at 0.4mm and are identifiable to species. When very small, the arm is most of the seastar diameter (G. Parry, pers. comm)

Slipway operators and clubs

- Hobson's Bay slipway - Yardman for the slipway said he saw them in the water (26/07/02). They are never on the boat hull but do get onto to the cradles that skip the boats.
- Royal Melbourne yacht club slipway - services smaller vessels < 50ft has never seen one on a hull or on any made-made gear used on slips.
- Royal Victorian Motor club (Williamstown) – consists of motorised vessels, mostly operated in Port Phillip Bay. Moored vessels are slipped at least once a year. Seastars have been seen on the slipway and ramp but never on the hull.
- Sandringham Yacht Club – consists of ~35ft sailing boats, mostly operated in Port Phillip Bay. Boats are cleaned at least once a year by scrubbers or on the Club slipway. Never observed a seastar on the hull of any boat being cleaned.
- Frankston yacht Club – consists of lightweight yachts (trailer sailers), with no moorings at the club. Never observed a seastar on the hull of any boat.

APPENDIX F RESEARCHERS WITH FOULING EXPERIENCE

1. Dr Wendy Barron (University of the Gold Coast) – studies hydrocarbon contamination on plates left in the water for twenty-four hours at St Kilda Pier.

24/07/2002 - "We only had our test frames in the water for 24 hours at St Kilda. In that time only bacterial growth normally occurs therefore no starfish. I don't know much about the starfish but I am guessing the one you are studying is the one that has invaded Tasmanian waters. We spent a long while watching them sucking the mussels from their shells in the marina at the Royal Yacht Club of Tasmania while we were there. That was the only time I recall having seen them in our travels up the whole East Coast. You could talk to John Lewis at DSTO as he has test frames in Port Phillip Bay and does a taxonomy of the growth organisms quite regularly"

2. Dr John Lewis (Defence, Science and Technology Organisation). Has an experimental raft in Port Phillip Bay (Port Piers) for evaluating the performance of new and experimental antifouling and fouling control coatings

10/12/2002 - "We have only very occasionally (one that we can remember) seen *Asterias* on either the structure or test panels on our raft, which is located between Gellibrand Pier and the mouth of the Tenix drydock. However I will do a conscious check next time we are there, which should be just before Christmas.*Undaria* is another matter, and we were invaded this winter/spring after not seeing a single plant in previous years. We also have lots of Sabella.

31/1/2003 - We were out on our test raft this morning and I kept an eye out for *Asterias*- there were none visible on either test panels, panel support frames or on the raft structure itself. The significant find was a plant of *Codium fragile subsp. tomentosoides* on a panel frame- the first time I have seen this on the raft and possibly (?) the first record for Hobsons Bay/Port of Melbourne

3. Dr Geoff Rigby – Consultant on hull fouling

18/09/2002 – "No, I have not any direct evidence of seastars on ship's hulls. However in my discussions with colleagues, it would certainly seem possible for NPS to be present (given the right location, time of berthing, conditions etc) on a heavily fouled vessel's hull."

4. Mr Tim Dodgshun - Marine Biosecurity Research Group, Cawthron Institute, New Zealand. The New Zealand group is conducting a study on entrained communities in ship sea chests.

24/09/2002 - "Fortunately we have not seen any *Asterias* (or any other sea stars) in sea chests of the vessels we've looked at so far. If we had seen the NPS there would have been pandemonium, as it has never been found in NZ waters. My gut feeling is that sea stars could easily be sucked into sea chests as larvae or small juveniles and later spawn there or escape into a new environment without much difficulty."

24/09/2002 - "Just a thought. If they do things in slipways in Oz like they do here, the sea chests are treated with a pretty thorough and violent water blasting both before and after the grilles are taken off. This might well reduce any sea stars to sea star soup. Hence not easily identified?"

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