

Mapping and distribution of *Sabella spallanzanii* in Port Phillip Bay

**Final Report to
Fisheries Research and Development Corporation
(FRDC Project 94/164)**

**G.D. Parry, M.M. Lockett, D.P. Crookes,
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May 1996

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Technical and Non-technical Summary

- The sabellid polychaete *Sabella spallanzanii*, a native to the Mediterranean, established in Port Phillip Bay in the late 1980s. Initially it was found only in Corio Bay, but during the past five years it has spread so that it now occurs throughout the western half of Port Phillip Bay.
- Densities of *Sabella* in many parts of the bay remain low but densities are usually higher (up to 13/m²) in deeper water and they extend into shallower depths in calmer regions.
- *Sabella* larvae probably require a 'hard' surface (shell fragment, rock, seaweed, mollusc or sea squirt) for initial attachment, but subsequently they may use their own tube as an anchor in soft sediment.
- Changes to fish communities following the establishment of *Sabella* were analysed using multidimensional scaling and BACI (Before, After, Control, Impact) design analyses of variance.
- The only measurable effect of the spread of *Sabella* on fish communities was an increase in the abundance of little rock whiting, which uses the habitat created by the forest of *Sabella* tubes.
- No fish has been found to prey on *Sabella* in the field.
- King George whiting actively rejected *Sabella* in laboratory feeding trials, probably because their feeding crowns contain particularly high levels of vanadium.
- The long term effects of *Sabella* on fish communities may be considerable as particulate food is channelled away from native filterfeeders and progressively into trophic pathways that may lead only to bacterial breakdown upon their death.
- *Sabella* may also significantly affect the growth and survival of other epifauna with which they compete for food and suitable settlement surfaces.
- Review of literature on the biology of the 20 most abundant exotic species in Victorian waters indicated that the exotic species which appear to be having the greatest impact are *S. spallanzanii* and the bivalve *Corbula gibba*. Other species causing considerable, but less concern, were the small sabellid *Euchone* sp, the majid crab *Pyromaia tuberulata*, and the Asian mussel *Musculita senhousia*. Priority should be given to these species in future research.

Introduction

This final report for the FRDC funded project "Mapping and distribution of *Sabella spallanzanii* in Port Phillip Bay" is considered in two sections: The first section contains original data collected during this project to satisfy Objectives 1, 2 and 3 and is organised to be suitable for publication in Marine and Freshwater Research. The second section contains the literature review required to satisfy Objective 4 and will be produced as a VFRI Technical report. Details of the methods, results and interpretation of results are presented in each of these sections and are included in this report as Appendices 1 and 2.

Background

In 1993 scallop fishers in Port Phillip Bay first noticed a large exotic worm, *Sabella spallanzanii*, in their catches. Since then catches of this species have increased and *Sabella* is now a major nuisance for scallop fishers as it clogs dredges and increases the labour required to sort scallops. *Sabella* causes similar problems for snapper fishers. Flathead caught on snapper longlines become so entangled with *Sabella* tubes that longlines are no longer able to be used in much of the 500 km² Geelong Arm of Port Phillip Bay. In 1994 *Sabella* was found in Western Australia and South Australia where a number of well-separated but still small populations are known to exist.

Two recent studies at VFRI (Currie *et al.* 1996 and Hobday *et al.* 1996) have documented significant changes to bottom communities and fish communities in Port Phillip Bay during the last 20 years. The major changes to bottom communities appear to be caused by the recent introduction of at least four exotic species. At least some of the changes observed to fish communities in Port Phillip Bay appear to be indirect consequences of these changes to bottom communities. Of particular concern is that half of the 12 exotic species known to have established in Port Phillip Bay are filterfeeders likely to compete for food with commercially important species such as scallops, oysters and mussels.

The four filter feeding species of greatest concern are the large sabellid, *Sabella spallanzanii*, the small sabellid *Euchone* sp., the Asian mussel, *Musculista senhousia*, and the bivalve mollusc *Corbula gibba*. In March 1994 *Sabella* was abundant throughout the Geelong Arm (Parry unpublished data). The limited circulation of water in the Geelong Arm and the short larval life of *Sabella* appear to have restricted its spread to the Geelong Arm for 5 years but having reached the end of the Geelong Arm it is seemed likely to spread throughout all available habitat in Port Phillip Bay within three years. The high biomass of this species means that it is likely to compete significantly for food with all native species including scallops, oysters and mussels. *Sabella* has established in such high densities (up to 300/m²) that it may also be able to outcompete species such as mussels for space. Coincident with the spread of *Sabella* in the Geelong Arm has been a marked decline in the snapper fishery in this area (Fig. 1).

Ecological studies on all these species are required eventually to:

- (1) determine the significance of their impacts,
- (2) document their breeding cycles to control uptake of ballast water and hence control their spread,
- (3) control their abundance.

These studies built on other VFRI monitoring programs in Port Phillip Bay, which were designed for different purposes, but which could be cheaply extended to provide much needed information on *Sabella*.

Need

The exotic sabellid worm *Sabella* has proven a major nuisance to the scallop and snapper fishermen in Port Phillip Bay because they interfere with fishing techniques. The longterm effects of *Sabella* on the fishing industry are also of concern as *S. spallanzanii* may alter the ecology of the bay, particularly through their competition for food and space with scallops, oysters and mussels.

Changes to fish communities have been monitored as *Sabella* spread further into Port Phillip Bay so that changes could be accurately documented and attributed to the correct cause.

A description of the habitat requirements was required to predict the likely scale of the problem when all suitable habitats were colonised.

The literature review of the biology of all exotic invertebrates known to occur in Victorian waters provided a means of establishing a ranking of species according to the threat they pose to local ecosystems. This will be of value in establishing research priorities.

Objectives

The project had four objectives:

1. Describe the habitat requirements of *Sabella spallanzanii* in the Geelong Arm and map the distribution of the worm *S. spallanzanii* in Port Phillip Bay during 1995.
2. Determine whether there have been changes to fish communities in regions of Port Phillip Bay affected by *S. spallanzanii*.
3. Identify the significance of *S. spallanzanii* in the diets of fish in Port Phillip Bay.
4. Describe the distribution, breeding cycles and larval duration of all exotic species found in Port Phillip Bay in their natural habitats, from published sources.

Objectives 2, 3, 4 and the mapping component of Objective 1 were fully achieved. We more than met Objectives 2 and 3. Objective 2 was more thoroughly investigated by the inclusion of information obtained from trawling during 1996. This additional work was funded by VFRI. Additional investigations were undertaken as part of Objective 3 once it became clear that no fish were eating *Sabella*. Laboratory feeding trials were conducted which showed King George whiting actively reject *Sabella*. Further chemical analyses of *Sabella* were then undertaken and these suggested a novel explanation for the unpalatability of *Sabella* to fish. *Sabella* contain very high levels of vanadium which appears to discourage fish from eating them.

Most elements of the habitat of *Sabella* were identified in Objective 1 but we remain unable to identify all the features that make particular reefs suitable as a habitat. Further work is required to establish the substrate requirements for successful recruitment to better predict the area of Port Phillip Bay likely to be affected by *Sabella* in the longterm.

Methods

These are described in detail in the methods sections of Appendices 1 and 2.

The video sled developed during the course of this study is worthy of further elaboration. This video system employed a shark cat (a much smaller vessel than we had used for this type of work before) and enabled a 2 man crew to produce very high quality video images of the sea floor. The permanent recording of latitude, longitude, date, time and depth on the video image greatly improved the ease and accuracy of analysis. This technique requires a computer with a suitable video card but these are relatively cheap and could be usefully employed in many applications.

Results

These are described in Appendices 1 and 2.

The distribution of *Sabella* has been expanding eastwards and northwards since its establishment in Corio Bay in the late 1980s. *Sabella* was found attached to a range of 'hard' substrates including algae, oysters, sea squirts and scallops as well as on man-made structures such as jetty pylons. Changes to fish communities caused by the spread of *Sabella* were small where *Sabella* densities were low. However a statistically significant increase in the abundance of little rock whiting occurred in the Geelong Arm following the establishment of *Sabella*.

No fish consumed *Sabella* in the field, and King George whiting actively avoided eating *Sabella* during laboratory trials. Chemical analyses indicated that *Sabella* contains very high levels of vanadium which may explain their unpalatability to fish.

Benefits

These studies suggest that to prevent further translocation of *Sabella spallanzanii* throughout southern Australia mechanisms to ensure fouled vessels do not transport this species are required. Further controls on ballast water discharge are unlikely to reduce the spread of this species.

Documentation of the rate of spread of *Sabella spallanzanii* and monitoring of associated changes to fish communities have identified only small changes to fish communities but have provided a baseline against which any future impacts may be detected.

Recognition that *Sabella spallanzani* has no predators and identification of the likely chemical basis for their unpalatability to fish predators has important ramifications for future impacts on Port Phillip Bay and elsewhere. Similarly identification of potentially

strong competitive interactions with other epifauna suggests that the abundance of epifauna should be closely monitored in future.

Intellectual property

No intellectual property has arisen from the research that is likely to lead to significant commercial benefits, patents or licences. Intellectual property associated with data produced from the project will be shared equally by the Fisheries Research and Development Corporation and the Victorian Department of Natural resources and Environment.

Further development

While only small effects have so far been measured on fish communities as a result of the spread of *Sabella* continued monitoring of fish communities is required because: (1) *Sabella* is continuing to spread within Port Phillip Bay, (2) *Sabella* may become more abundant, (3) the statistical tests employed are not sensitive because of large natural interannual variation in fish communities, and (4) significant changes to the trophic structure may result from the unpalatability of *Sabella* to fish.

Improved monitoring of changes in epifaunal species (scallops, mussels, oysters and sea squirts) is required as these species appear particularly vulnerable to the continued presence and further spread of *Sabella*.

Staff

Organisation, position, period on project and percentage of time while on project are listed for each staff member.

Victorian Fisheries Research Institute, Department of Conservation & Natural Resources

Dr Greg Parry	Principal Investigator	1 Jan 95-1 Jan 96	30%
Dr Noel Coleman	Marine Scientist	1 Jan 95-1 Jan 96	25%
Mr Matthew Lockett	Technical Officer	1 Jan 95-1 Jan 96	40%
Ms Dianne Crookes	Technical Assistant	1 Jan 95-1 Jan 96	40%

Department of Ecology and Evolutionary Biology, Monash University

Mr Michael Sinclair	PhD student	1 Jan 95-1 Jan 96	4%
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Final Cost

Details of grant and expenditure are in the following tables. Expenditure on the project was \$984 greater than the total grant. The additional expenditure above the initial allocation is not sought from FRDC.

Budget item	Grant (\$)			
	1994/95	1995/96	1996/97	Total
<u>Project grant</u>				
Salaries	45250			45250
Operating expenses	16000			16000
Travelling expenses	5,000			5,000
Capital items	0			0
Total	66250			66250
<u>Expenditure</u>				
Salaries	22102	22102		44204
Operating expenses	12,450	6943		19393
Travelling expenses	2657	980		3637
Capital items	0	0		0
Total	37209	30025		67234

Distribution

This report is being distributed to researchers who have an interest in exotic species research, Port Phillip Bay and its fisheries.

Australian Fisheries Management Authority
Burns Centre, 28 National Circuit, Forrest ACT 2603

Australian Institute of Marine Science
PMB No 3, Townsville QLD

Australian Maritime College
Beauty Point, TAS 7270

Bureau of Resource Sciences, Fisheries Resources Branch
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CSIRO Marine Laboratories, Division of Fisheries
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Marine Resources Division, Department of Primary Industry and Fisheries
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National Fishing Industry Council
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South Australian Fishing Industry Council
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South Australian Research and Development Institute
GPO Box 1671, Adelaide SA 5001

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Tasmanian Sea Fisheries Research Laboratories
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Acknowledgments

Thanks to Brett Matthews, John Barry and Ian Duckworth who developed the video sled and associated computer interface. Arnold Jahnecke, Mark Ferrier and Ian Duckworth assisted with the video field work and dived on most of the piers with some assistance from Michael Holloway (Zoology Department, University of Melbourne). Thanks also to Dave Beyer and the crews involved in both trawling and diver surveys of *Sabella* distribution and to Gus Fabris who undertook the chemical analyses.

References:

Currie D.R., Parry G.D., Poore, G.C.B. and Wilson R.S. (1996) Changes to benthic communities in Port Phillip Bay over 20 years. Submitted to Australian J. Ecology.

Hobday, D. Officer, R.A. and Parry (1996) Changes to fish communities in Port Phillip Bay over two decades: 1970-1991. Draft report provided to CSIRO Port Phillip Bay Environmental Study. In preparation for submission to Marine and Freshwater Research.

APPENDIX 1

**THE SPREAD AND ECOLOGICAL EFFECTS OF THE EXOTIC
POLYCHAETE *SABELLA SPALLANZANII* WITHIN PORT PHILLIP BAY.**

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ABSTRACT

Gregory D. Parry, Matthew M. Lockett and Dianne P. Crookes. (1996) The spread and ecological effects of the exotic polychaete *Sabella spallanzanii* within Port Phillip Bay.

The sabellid polychaete *Sabella spallanzanii*, a native to the Mediterranean, established in Port Phillip Bay in the late 1980s. Initially it was found only in Corio Bay, but during the past five years it has spread so that it now occurs throughout the western half of Port Phillip Bay. Densities in many parts of the bay remain low but densities are usually higher (up to 13/m²) in deeper water and the worm's distribution extends into shallower depths in calmer regions. Larvae probably require a 'hard' surface (shell fragment, rock, seaweed, mollusc or sea squirt) for initial attachment, but subsequently they may use their own tube as an anchor. The only measurable effect of the spread of *S. spallanzanii* on fish communities was an increase in the abundance of little rock whiting, which uses the habitat created by the forest of *S. spallanzanii* tubes. No fish has been found to prey on *S. spallanzanii*, possibly because their feeding crowns contain particularly high levels of vanadium.

The channelling of particulate food away from native filter-feeders may have considerable long term effects on fish communities. As the density and coverage of *S. spallanzanii* increases more energy may be channelled into trophic pathways that appear to lead only to bacterial breakdown upon the death of the worms. *S. spallanzanii* may also significantly affect the growth and survival of other epifauna with which they compete for food and suitable settlement surfaces.

INTRODUCTION

The transfer of species across natural oceanic barriers by international shipping has led Carlton and Geller (1993) to suggest that bays, estuaries and inland deepwater ports may be amongst the world's most threatened ecosystems. Major disruptions to the Great Lakes in North America have been caused by introduction of the zebra mussel, *Dreissena polymorpha*, which occurs in densities up to 700,000/m² (Griffiths *et al.* 1991; Strayer 1991) and to fisheries in the Black Sea by the exotic ctenophore *Mnemiopsis leidyi* (Vinogradov *et al.* 1989), which within two years of its establishment had a biomass of 1.5-2 kg/m², an order of magnitude greater than that of all other plankton.

All exotic species alter natural interactions in the invaded ecosystems, but not all pose serious threats to these ecosystems. Unfortunately identifying species likely to establish in new ecosystems is difficult, as is predicting their likely impact (Hengeveld 1989). There are now approximately 20 species that are known to have established in Victorian waters (Coleman and Sinclair 1996). Not all of these species appear to be causing major disruptions but a number of species are causing concern as they occur in large numbers. Of these 'pest' species *Sabella spallanzanii*, a native of the Mediterranean (Clapin and Evans 1995), is clearly the most conspicuous. It is large, up to 50 cm in length, and may occur in high densities (up to 300/m²). In parts of the Geelong Arm of Port Phillip Bay it forms a continuous covering over areas of 100's of square metres.

In contrast to the situation with many introductions *Sabella spallanzanii* was detected shortly after its establishment in Port Phillip Bay and the first semi-quantitative data on its distribution were obtained within approximately two years of its establishment. That this introduction was detected early, before the entire habitat was affected, has enabled changes to fish communities to be measured during its spread to new areas. This study documents the spread of the exotic polychaete *S. spallanzanii* and interprets quantitative data on its density and possible ecological effects, particularly on fish communities.

METHODS

Trawling

Fish and *Sabella spallanzanii* were collected annually using a wing trawl net (47 m long, 13 m wing spread, 5m opening height and 45 m between trawl doors) at 22 depth-stratified stations in Port Phillip Bay (Fig. 1) between 1990 and 1996. Sampling stations were located on 6 transects perpendicular to the coastline. Two trawl shots were taken at depths of 7, 12, 17, and 22 m on all transects except those in the Geelong Arm where depths permitted trawling only at 7 and 12 m. The duration of each trawl shot was 5 minutes, measured from the time load cell clamps were attached until the winch commenced the retrieval of the net. Data obtained using a

netsonde indicated that the net was probably fishing for an additional 2 minutes during its retrieval. A Furuno GP 500 GPS Navigator connected to a colour video plotter was used for all position fixing and was accurate to within 15-25 m in 95% of fixes. Where inaccuracy exceeded 25 m due to intentional degradation of the system (selective availability) this was obvious on the plotter. The speed of the net across ground, 2.1-2.5 knots, was estimated from the latitude and longitude at the start and finish of each shot and the duration of each shot.

Fish were sorted on deck and the number and total weight of each species was recorded. The total number of *Sabella spallanzanii* in each trawl was also counted. Where very large numbers of *S. spallanzanii* were collected the number of fish bins of worms was determined and the number of *S. spallanzanii* in a fish bin measured subsequently.

The number of *Sabella spallanzanii* attached to different substrates was recorded for all trawl shots, except when rough weather or large catches of jelly fish made this task difficult. The numbers of scallops, oysters and *Pyura stolonifera* available as settlement substrate and the numbers of these on which *S. spallanzanii* had recruited were also recorded.

Diver surveys of *Sabella* distribution

Each March during 1994, 1995 and 1996 the number of *Sabella spallanzanii* at 65-70 sites in Port Phillip Bay was counted by divers. Sites were well-distributed throughout the bay, but were concentrated in regions which usually supported commercial scallop populations. At each site two 50 × 1 m transects were surveyed and the number of *S. spallanzanii* on each transect was recorded. When the number of *S. spallanzanii* exceeded 10 the number of worms per 50 m transect was recorded as an abundance class, either 11-100, or >100. Where abundance classes differed between both transects on the same site the transect with the higher number of worms was used to plot distribution maps.

During April 1995 divers surveyed the number of *Sabella spallanzanii* and other epifaunal species on 25 piers located around the perimeter of Port Phillip Bay. On each pier weighted lines marked at 1 m intervals were attached at approximately the low water level on 4 pylons. Divers recorded a visual estimate of the percentage cover of all epifauna on these pylons in 1 m depth intervals. At each site the average percentage cover of epifaunal species was calculated for each depth interval. Where no *S. spallanzanii* were recorded on the four pylons a further 16 pylons were examined to determine whether *S. spallanzanii* was attached to any of these. If *S. spallanzanii* was not recorded on 20 pylons it was considered absent from that site. During April 1996, 20 pylons on ten of the piers without *S. spallanzanii* during 1995 were again searched for *S. spallanzanii*.

Video survey of Geelong Arm

The density of *Sabella spallanzanii* was estimated in the Geelong Arm where this species was most abundant and its impact likely to be greatest. The survey was undertaken using an underwater video camera attached to a towed sled. A video camera was located 0.5 m above the seabed and had a field of view 0.60 m (wide) ×

1.0 m (long). A Trimble navigation NavtracXL differential GPS, connected to a Traxar MRB-1A MSK radiobeacon receiver was used to record the position of the tow vessel and a Furuno FCV-581 sounder used to record depth. A computer was used to integrate information from the GPS and sounder to enable latitude, longitude, time and depth to be recorded continuously on the video tape. The underwater video was towed at ~1.5 knots on 13 transects perpendicular to the shoreline. On each transect the video was towed for 7 min. along the 2, 4, 6 and 8 m depth contours. The number of *S. spallanzanii* in each 1:45 min segment of the video tape was counted and the latitude and longitude at the start and finish of each 1:45 min period used to calculate the area swept during this period. For each depth interval on each transect the mean density and standard error were then calculated from the average of the density estimates for each 1:45 min sector of the video. (At 1.5 knots the video will travel ~80 m in 1:45 min). Where reef occurred on a transect it was not possible to use the video sled.

Statistical analysis of changes to fish communities

Significant expansions in the range of *Sabella spallanzanii* occurred after 1991 (when *S. spallanzanii* first became established at the Geelong 12 m site, Fig 2a) and after 1994 (when *S. spallanzanii* first became established at many sites, Fig 2a). Thus differences in fish community structure were compared between three periods: 1990-91, 1993-94 and 1995-96. Differences between fish community structures before and after establishment of *S. spallanzanii* were examined for these three periods using both multidimensional scaling (MDS) and analysis of variance (ANOVA).

Spatial differences between fish communities at the 22 stations and temporal differences between the three periods were examined with MDS using Bray-Curtis (B-C) dissimilarity measures (Bray and Curtis 1957). The B-C dissimilarity measure is given by the following relationship:

$$\delta_{jk} = \frac{\sum_{i=1}^s |n_{ij} - n_{ik}|}{\sum_{i=1}^s (n_{ij} + n_{ik})}$$

where n_{ij} = the number of the i th species in the j th sample, n_{ik} = the number of the i th species in the k th sample and δ_{jk} = dissimilarity between the j th and k th samples summed over all s species. This dissimilarity measure was chosen because it is not affected by joint absences, it gives more weighting to abundant than rare species, and it has consistently performed well in preserving 'ecological distance' in a variety of simulations on different types of data (Field *et al.* 1982; Faith *et al.* 1987). Double square root ($=N^{1/4}$) transformations were applied to all data before calculating B-C dissimilarity measures. These transformations were made to prevent abundant species from influencing the B-C dissimilarity measures excessively (Clarke and Green 1988; Clarke 1993). MDS plots were used to ordinate B-C dissimilarity measures. MDS translates a measure of similarity between measurements into 2 or more dimensional space so that distances between measurements correspond closely to their input similarities. While the computational algorithm for MDS is complex the graphical representation is easily communicated (Clarke 1993) and ecologically meaningful patterns are made more apparent (Gamito and Raffaelli 1992). The PATN computer

package (Belbin 1990a, b) was used for the non-metric MDS ordinations used in this study. The goodness of fit of each MDS plot is given by its stress value. Stress values <0.1 correspond to a good ordination, values >0.1 and <0.2 are useable, but those near 0.2 may mislead and values >0.2 are likely to yield plots that are difficult to interpret (Clarke 1993).

Changes to the abundance of individual species of fish following the establishment of *S. spallanzanii* at particular trawl stations were assessed by comparing changes with those that had occurred in other similar areas but where *S. spallanzanii* had not yet established. This BACI (Before, After, Control, Impact) experimental design (Stewart-Oaten *et al.* 1986) should discriminate between the effects caused by *S. spallanzanii* and other temporal trends. Statistical significance of the effect of *S. spallanzanii* was tested using nested ANOVA in which area $\times$ time interactions were tested against the mean square for the area $\times$ year (effect) term. This test is equivalent (Underwood 1991), Table 2c) to the t-test recommended by Stewart-Oaten *et al.* (Stewart-Oaten *et al.* 1986). Homogeneity of variance was examined using Cochran's test and heterogeneity removed by $\log_{10}(N+1)$. Previous studies (Parry *et al.* 1995) had indicated that Corio Bay has a distinctive fish community, but throughout the remainder of the bay there are only three depth-related fish community types. These three community types were used to match *Sabella* impacted sites with suitable control sites that had not yet been affected by *Sabella*. Four BACI analyses were undertaken: changes at the Geelong 12 m site (g12, Fig. 1) were compared with changes at Mornington 12 m site (m12, Fig. 1) and the St Leonards 12 m site (s12), before and after 1992 (when *Sabella* established at g12, Fig.1), changes at w7 were compared with changes at s7, h7, b7 and m7, before and after 1994 (when *Sabella* established at w7, Fig.1), changes at w12 and w17 were compared with changes at m12 and s12, before and after 1994 (when *Sabella* established at w12 and w17, Fig.1), and changes at w22 and h22 were compared with changes at h17, b22 and m22, before and after 1994 (when *Sabella* established at w22 and h22, Fig.1).

Analysis of fish diets

During late February 1994 the gut contents of 10 individuals of all abundant fish species were analysed from fish collected at the 2 trawl stations in the Geelong Arm (Fig. 1). During March 1995 these trawl stations were resampled as were three additional stations near Pt Henry, near Wilson Spit and east of Pt Wilson (Fig. 1). Stomach contents were analysed from the 16 species of fish considered most likely to eat *Sabella spallanzanii*, based on recent analyses of stomach contents of more than 6500 fish of 35 species in Port Phillip Bay (Parry *et al.* 1995; Officer and Parry 1996a). Fish were collected from two stations in the Geelong Arm in 1994 and from five stations in 1995 and stomach contents of no more than 10 individuals of a species were analysed from a single trawl shot. Stomachs were removed from larger fish as soon as possible after capture and placed in buffered formalin. The body cavities of smaller fish were opened on the vessel to ensure formalin penetrated quickly into their digestive system which was removed later in the laboratory. While fish were stored by shot on the vessel they were re-sorted by species in the laboratory to increase the speed and accuracy of the identification of stomach contents. The number and total volume of individual prey items in each stomach were recorded for each fish species. Volume was estimated by evenly spreading each prey item over graph paper next to an

L-shaped perspex segment of known height (1.5 mm, 2.5 mm, 4 mm or 6 mm) and counting the number of 2 mm by 2 mm squares covered by the prey (Windell 1971).

Species of prey were identified by comparison with an extensive reference collection of benthic invertebrates from Port Phillip Bay. The identity of each species in the reference collection was confirmed by Drs G. Poore (Crustaceans) and R. Wilson (Polychaetes) and Ms S. Boyd (Molluscs) from the Museum of Victoria.

Feeding preference trials

As no fish appeared to eat *S. spallanzanii* in the field, laboratory feeding trials were conducted to determine whether fish actively rejected *S. spallanzanii*. King George whiting were chosen for these trials as they feed extensively on polychaetes in Port Phillip Bay (Parry *et al.* 1995) and, unlike eastern shovelnose stingarees which also feed extensively on polychaetes (Parry *et al.* 1995), they have no obvious morphological constraints that may prevent them from feeding on *S. spallanzanii* in the field.

On 23 November 1996, 12 King George whiting (24.5 ± 1.5 cm length) were collected and maintained in four 60 L glass aquarium tanks. Tanks were surrounded by black plastic to reduce disturbance. Three fish were placed in each tank and acclimated until food added one day was eaten by the following day. After 7 days, food was being consumed by fish in all tanks and feeding trials were commenced. In each trial three worms (Fam. Arenicolidae, Neridae and obtained from sand flats at Queenscliff) were placed in two (control) tanks, three *S. spallanzanii* were removed from their tubes and placed in another tank and three *S. spallanzanii* still in their tubes were placed in a further tank. All worms offered to fish were of similar size (6.5-10 cm). For nine days the number of worms eaten was recorded daily and any eaten worms replaced. After 3 days and 6 days the treatment applied to each tank was changed so that all fish were exposed to every treatment.

Chemical analyses

As King George whiting actively rejected *Sabella spallanzanii* in laboratory feeding trials the possible chemical basis for this rejection was investigated. Ten *S. spallanzanii* were collected from Queenscliff 'cut' during October 1995. The feeding crowns were separated from the remainder of the worms, each fraction weighed, then frozen and freeze-dried. The dried material was weighed and homogenised in a blender, and stored over silica gel until required for analysis. The digestion and analytical procedure used for determination of Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, Vanadium and Zinc was based upon that of the United Nations Environment Programme (UNEP/FAO/IAEA 1982), with the modification that boro-silicate glass tubes were used for the digestions. A sample of each freeze-dried tissue was heated with 10 mL concentrated nitric acid at 90°C on a hot plate until all the tissue had been digested. After cooling, solutions were diluted to 30 mL with water. All metals were determined by flame atomisation AAS. A deuterium arc was used for background correction in all cases.

RESULTS

During 1990 Corio Bay was the only one of 22 stations in Port Phillip Bay at which *Sabella spallanzanii* was recorded. By 1993 *S. spallanzanii* had spread to the central part of the Geelong Arm (Fig. 2a) and by 1994 to the eastern end of the Geelong Arm (Fig. 2b). By 1995 *S. spallanzanii* had spread further north to regions off Werribee and to deeper sites off Hobsons Bay and St Leonards (Figs 2a, b). Between 1995 and 1996 *S. spallanzanii* established at all but the shallowest areas off Hobsons Bay and spread further east to the region off Beaumaris (Figs 2a,b). However between 1995 and 1996 the density of *S. spallanzanii* off Werribee appeared to increase based on captures in the trawl net (Fig. 2a) but clearly decreased based on diver counts (Fig. 2b).

The distribution of *S. spallanzanii* on piers in 1995 and 1996 was consistent with the pattern of their spread further offshore. *S. spallanzanii* was found on all piers on the west of Port Phillip Bay between Pt Henry and Williamstown as well as on Portarlington pier and at one of three sites sampled at Queenscliff. *S. spallanzanii* was not found on any pier on the east of Port Phillip Bay between St Kilda and Portsea during 1995 or 1996.

Typically *S. spallanzanii* occurs in clumps on the seabed and 200-300 may be found in an area of 1 m². The Geelong Arm was the area of highest density in 1995 and quantitative estimates of density in this area indicated that the density varied from 0 to 13/m² averaged over areas of ~ 50 m² (Fig. 3, Table 1). Densities were low in shallow (2 m depth) regions and on most transects densities increased with depth.

The most common attachment surfaces for *Sabella spallanzanii* caught in trawl nets were bubble weed, oysters, scallops and *Pyura stolonifera* (Table 2). Bubble weed only occurs near Werribee (particularly at site w7), where it occurs attached to *Pyura stolonifera* and dead mollusc shells, although most occurs as drift algae. The highest density of *S. spallanzanii* identified in the video survey occurred on this drift weed near Werribee (Table 1, Fig. 3). Elsewhere in the bay most *S. spallanzanii* that attached to hard substrate were attached to oysters, scallops or *P. stolonifera*. The number of *S. spallanzanii* attached to each of these substrates varies throughout the bay depending on the relative abundance of these substrates, but a higher proportion of *P. stolonifera* and oysters than scallops were colonised by *S. spallanzanii* (Table 2). Most of the *S. spallanzanii* collected in trawls were in clumps and most *S. spallanzanii* were attached to other *S. spallanzanii*. Often the clump was not clearly attached to any hard substrate and at one site (w22-1995, Table 2) two of the three *P. stolonifera*, to which >30 *S. spallanzanii* were attached, were dead and decaying.

Sabella spallanzanii have established on fouling communities on pylons with several different dominant taxa (Fig.4). They have established on communities in which bare space, algae, *Mytilus planulatus* and *Pyura stolonifera* were the dominant organisms, but they have not yet established where sponges are the dominant taxa (Fig. 4). The minimum depth to which *S. spallanzanii* occurred varied between piers and was lower on more sheltered piers in Corio Bay and Williamstown, than on more exposed piers such as Pt Wilson (particularly), Pt Henry, Pt Cook and Altona. On most piers the

density of *S. spallanzanii* increased with depth, except where sediment scouring occurred near the base of some pylons.

MDS of fish community structure at 22 trawl sites sampled during 3 periods: 1990-91, 1993-94 and 1995-96 suggest that fish communities have not changed markedly in most areas following the establishment of *Sabella spallanzanii* (Fig. 5). There is no evidence that low densities of *S. spallanzanii* are affecting fish communities (Fig. 5). However fish community structure at sites g12 and w22 changed markedly in 1992 and 1994-95 respectively, when high densities of *S. spallanzanii* established at these two sites. Significantly both sites became more similar to site g7 in Corio Bay, where *S. spallanzanii* has been abundant since our trawl surveys commenced in 1990 (Fig. 5). The MDS indicates that Corio Bay is distinct from fish communities elsewhere in Port Phillip Bay and that fish communities change along a sediment/depth gradient as shown previously by Parry *et al.* (Parry *et al.* 1995). The high stress value (0.29, Fig. 5) is caused partly by the large number of points in the MDS (Clarke 1993) and partly because there are few clear patterns in the data, which provides further evidence that changes to fish communities due to *S. spallanzanii* are small.

ANOVAs of changes to the abundance of each species of fish on sites where *S. spallanzanii* had established compared those sites pre-impact and other unimpacted control sites detected significant change ($p < 0.10$) in the abundance of only one species, little rock whiting (Table 3) at one site (g12, Fig. 1). Little rock whiting was not found at g12 during 1990 and 1991, but became abundant from 1992 when *S. spallanzanii* established at this site (Fig. 2a).

Analysis of the diets of 298 fish of 16 species obtained from an area of high *S. spallanzanii* density in the Geelong Arm found no fish to have consumed any *S. spallanzanii*. During laboratory feeding trials with King George whiting no *S. spallanzanii* inside its tube was ever eaten and very few of those removed from their tubes were eaten (Table 4). Indeed 2 of the 3.5 *S. spallanzanii* eaten during the trials were eaten on the last day of the trials when the fish had been under-nourished for nearly a month (Table 4). Polychaetes other than *S. spallanzanii* were invariably eaten by the following day.

Concentrations of several heavy metals, including vanadium, were found to be high in *S. spallanzanii* and particularly high in their feeding crowns (Table 6).

DISCUSSION

Sabella spallanzanii was first noticed in Corio Bay by divers in 1988 (A. Stephens, EPA, personal communication), but was not detected in a quantitative benthic survey of this same area the previous year (Coleman 1993). The pattern of spread of *S. spallanzanii* is consistent with its establishment in Corio Bay from shipping in the late 1980s. While it may have established from international vessels visiting the Port of Geelong, it seems more likely that it was transported via Western Australia as *S. spallanzanii* appears to have been in Western Australia since at least 1965 (Clapin and Evans 1995) and there are many vessels that travel between Cockburn Sound and Geelong.

S. spallanzanii, in common with all sabellids, does not have feeding larvae (Rouse and Fitzhugh 1994). Consequently its larval life is probably less than 4 days and it would be unlikely to survive in ballast water long enough to be transported to Australia from the Mediterranean. As it is frequently found attached to the hulls of inadequately anti-fouled vessels hull transport seems the most probable mechanism of translocation for this species (Rainer 1995).

Most of the expansion of the range of *Sabella spallanzanii* in Port Phillip Bay during the 1990s appears consistent with the dispersal of short-lived larvae by the typically clockwise currents in Port Phillip Bay (Anon.1973). The distribution has expanded progressively eastward and then northward from Corio Bay. The establishment of *S. spallanzanii* in Queenscliff 'cut' and at Portarlington pier was probably the result of scallop fishermen discarding worms caught in their dredges in their home port. Significantly *S. spallanzanii* has not yet established on Mornington pier but 6 individuals were observed growing on the seabed during May 1996 near the berths of several scallop vessels. Similarly during May 1996 *S. spallanzanii* was found in Sandringham boat harbour (between St Kilda and Half Moon Bay, Fig. 1) (Lockett, personal observations) where it is likely to have been transported by pleasure craft.

On piers *Sabella spallanzanii* were found attached to *Pyura stolonifera*, *Mytilus planulatus* as well as attaching directly to pylons. Significantly *S. spallanzanii* has not yet invaded any sponge dominated communities, although these are mostly near the entrance to Port Phillip Bay and few larvae may have dispersed into this area. Significantly within this area the abundance of *S. spallanzanii* differed greatly between three sites at Queenscliff. *S. spallanzanii* were abundant on steel structures at the end of Queenscliff 'cut', near where they were discarded from scallop vessels, but they were absent from adjacent concrete pylons with nearly 100% cover of *Pyura stolonifera* and from wooden pylons dominated by sponge communities on Queenscliff pier. Significantly during 1995 and 1996, 50-60 *S. spallanzanii* were found within large concrete seawater storage tanks at Victorian Fisheries Research Institute (VFRI) which obtain their water from an intake beneath Queenscliff pier. Consequently communities at Queenscliff pier must have been exposed to larvae from *S. spallanzanii*. The growth of sponges on the pier may inhibit settlement of *S. spallanzanii* as there was minimal growth of any fouling organisms on the inside the dark cave-like storage tanks at VFRI where *S. spallanzanii* established.

Most *Sabella spallanzanii* found on the seabed occurred in clumps where it appeared that gregarious settlement had caused small individuals to recruit on the tubes of those which had already established. However asexual reproduction may also contribute to the formation of clumps. *S. spallanzanii* has considerable capacity to regenerate severed body parts (Kiortsis and Moratiou 1965) and in both Western Australia (Clapin and Evans 1995) and in this study animals that had clearly divided within a tube were observed where the animal in the basal section of the tube was growing a new crown and the animal in the front of the tube was regenerating the base of the tail.

Near Werribee where the highest densities were observed *S. spallanzanii* were mostly attached to drifting weed. Elsewhere in the bay most clumps were attached to a fragment of shell, oyster, *Pyura stolonifera* or scallop, which was probably the substrate upon which initial settlement had occurred. That a higher proportion of

oysters and *Pyura stolonifera* than scallops had *S. spallanzanii* attached to them suggests that the scallops may limit settlement of larval *S. spallanzanii* by burying themselves just below the sediment surface. Approximately 25% of clumps on areas of soft sediment had no obvious hard substrate to which the first member of the clump had attached. Furthermore even when worms were attached to a shell fragment this was usually well below (10-15 cm) the sediment surface. As the hard substrate was probably on the surface of the seabed when initial settlement occurred it appears that *S. spallanzanii* is able to grow down into the substrate and form an anchor with its own tube. All tubes in soft sediment have a pronounced U-shaped bend at their base, in which the inner edges of the U are joined. It appears likely from the growth lines on the U-shaped section that this part of the tube grows downwards and functions as anchor. As a hard surface is probably required for settlement, hard surfaces may be limiting in some locations but the remaining hard surfaces are probably at high risk of colonisation. In one location two dead *Pyura stolonifera* were found with many *S. spallanzanii* attached and it is likely that they were starved by the clump of *S. spallanzanii* surrounding them. Thus epifauna may be at particular risk from *S. spallanzanii*.

Changes to fish communities are not detectable where *Sabella spallanzanii* densities remain low. Where densities are high there appears to have been an increase in the abundance of the little rock whiting. This species is only common in areas of high *S. spallanzanii* density in Corio Bay and in the Geelong Arm where it is found swimming amongst *S. spallanzanii* tubes. Furthermore this species was not found in the Geelong Arm, outside Corio Bay, until *S. spallanzanii* established at station g12 (Fig.1) in 1992 which strongly suggests that *S. spallanzanii* is providing a habitat for little rock whiting. Little rock whiting do not eat *S. spallanzanii* nor do they appear to feed on epifaunal species that have settled on *S. spallanzanii* tubes (Table 4). It seems likely that the tubes primarily provide a refuge from predators for this small (20 cm) species.

Fish have not been observed feeding on *Sabella spallanzanii* in Western Australia (Clapin and Evans 1995) nor have they been found in the gut contents of any fish in Port Phillip Bay. This is distinct contrast to the consumption of other recently established exotic species in Port Phillip Bay, including *Corbula gibba*, *Pyromaia tuberculosa* which are consumed by a wide variety of fish (Parry *et al.* 1995; Officer and Parry 1996a). Although we have received reports from three recreational fishermen that sand flathead caught in Port Phillip Bay have regurgitated *S. spallanzanii* following capture. It is clear *S. spallanzanii* are actively avoided by King George whiting in laboratory trials and it seems likely that this avoidance is due to high levels of metals and particularly vanadium in their feeding crowns. Ishii *et al.* (Ishii *et al.* 1994) found very high levels (5500 µg/g dry weight) of vanadium in the crowns of the Japanese sabellid *Pseudopotamilla ocellata*, and noted that vanadium concentrations in most marine organisms, including other species of sabellids, are less than 25 µg/g dry weight. They suggested that since the brachial crown is the site of gas exchange that vanadium may have a role in oxidation-reduction reactions. However ascidians have been known to concentrate vanadium since early this century and there is no evidence that vanadium functions as an oxygen binding pigment in ascidians (Macara *et al.* 1979). Instead the functions suggested for vanadium in ascidians are anti-microbial, antipredation mechanisms and roles in excretion, tunic formation and

ornamentation (Martoja *et al.* 1994). The clear lack of palatability of *S. spallanzanii* to King George whiting supports that view that vanadium has an antipredation role in both ascidians and sabellids. Martoja *et al.* (1994) considered antipredation an unlikely role simply because all ascidians do not contain high levels of vanadium. However this is a spurious argument as it implies that predator avoidance is of equal significance to all species of ascidians. The argument is analogous to arguing that green is not an effective camouflage for birds because they are not all green. The functions of vanadium favoured by Martoja *et al.* (1994) are roles in tunic formation and ornamentation. But these roles are certainly inconsistent with vanadium having similar roles in both ascidians and sabellids, as sabellids do not have tunics.

The long term effect of *Sabella spallanzanii* on the ecology of Port Phillip Bay is difficult to predict. The diversion of particulate food into a trophic pathway that results in increased production of a species that appears to have no fish (or other) predator would be expected to reduce fish production. Interestingly, the region of Port Phillip Bay with the lowest consumption of invertebrates by fish is Corio Bay (Officer and Parry 1996b) where *S. spallanzanii* is most abundant. The only measurable effect of *S. spallanzanii* on fish communities at present is an increase in the abundance of the little rock whiting, apparently because the forest of tubes forms a suitable habitat.

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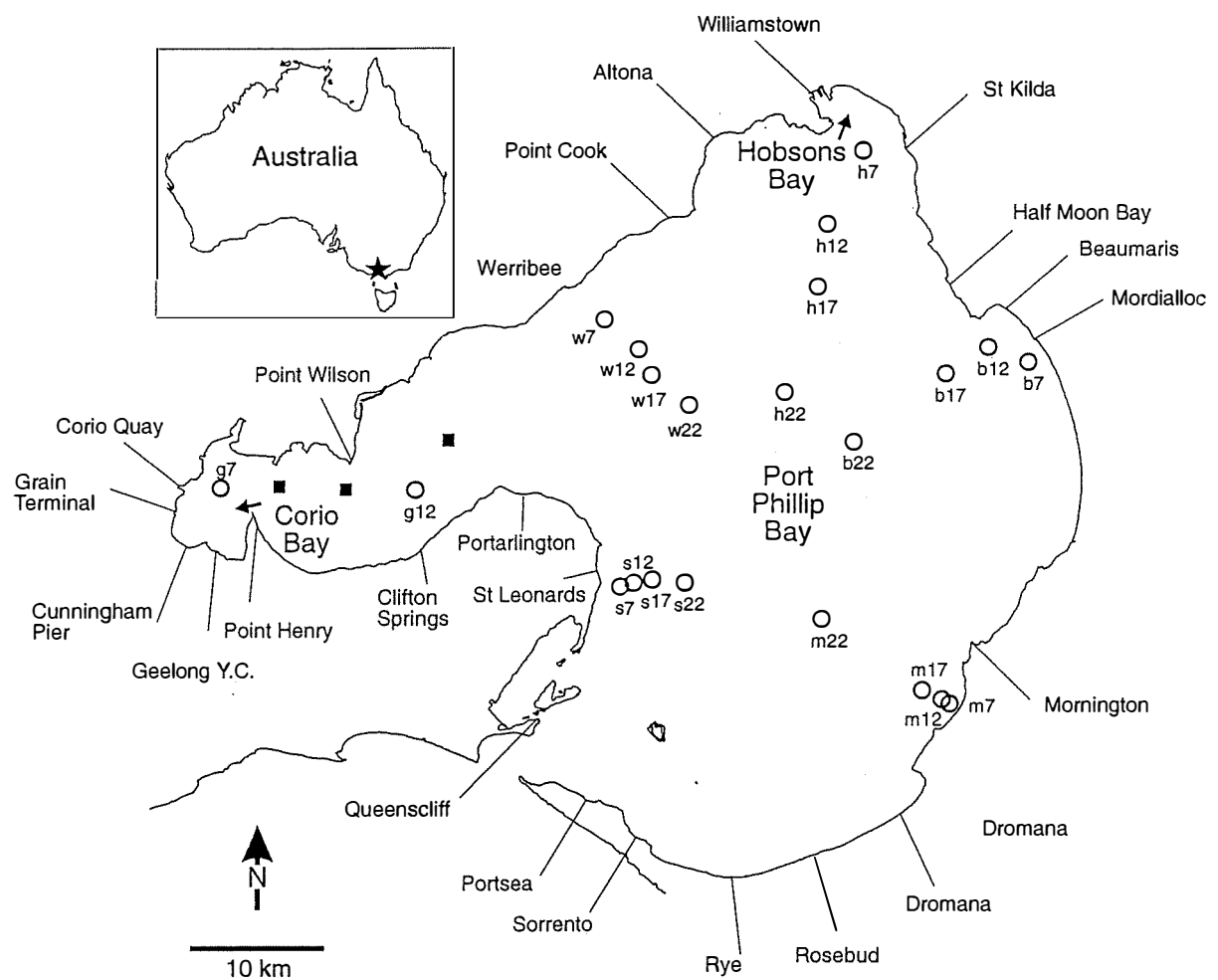


Figure 1. The location of Port Phillip Bay (inset) and the location of 22 trawl stations sampled between 1990 and 1996, and piers examined by divers in 1995. The code for each trawl station, which includes the depth in metres, is given. Filled squares indicate locations of additional trawl stations sampled in 1995 for analysis of fish diets.

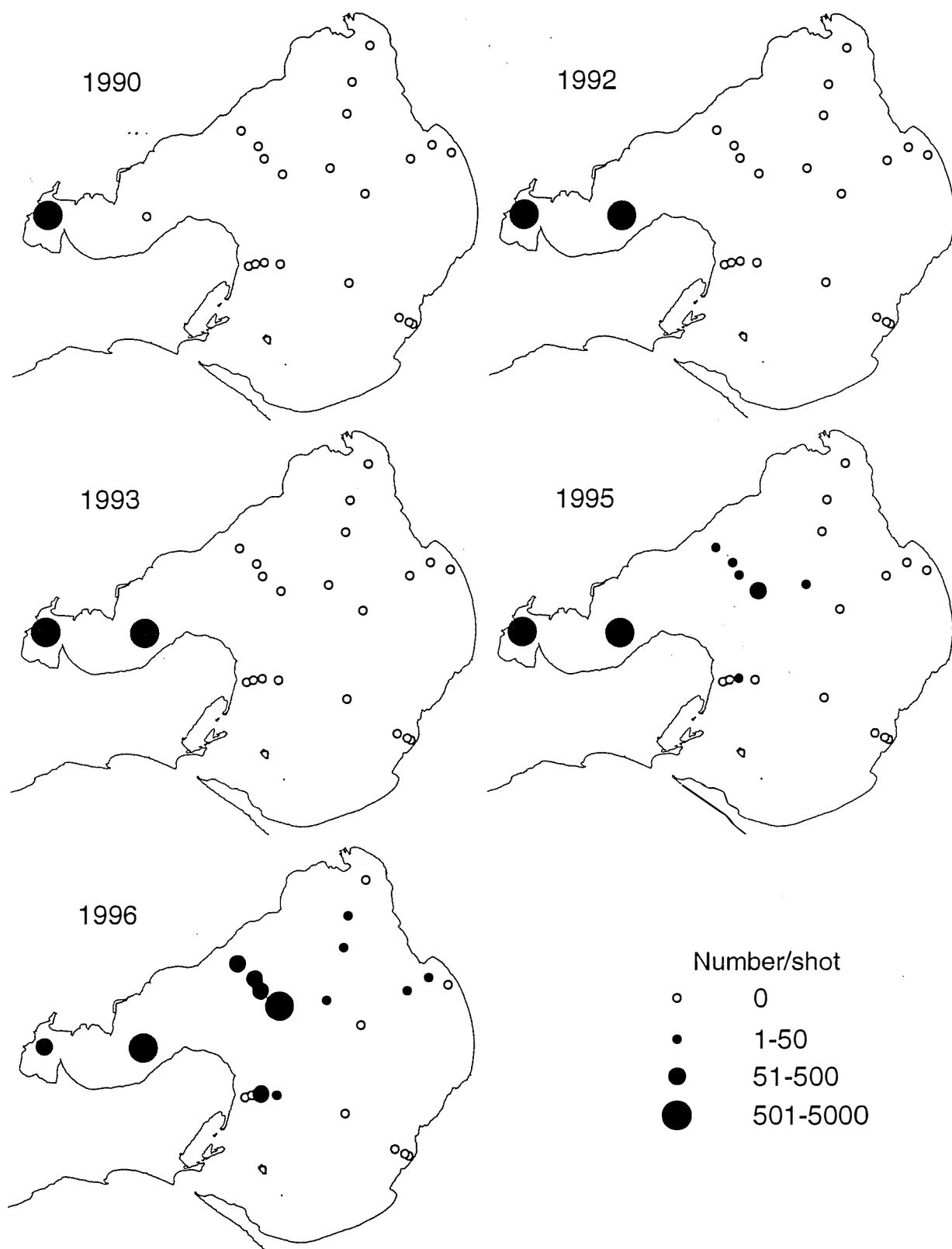


Figure 2 a. The density of *Sabella spallanzanii* at trawl stations sampled between 1990 and 1996.

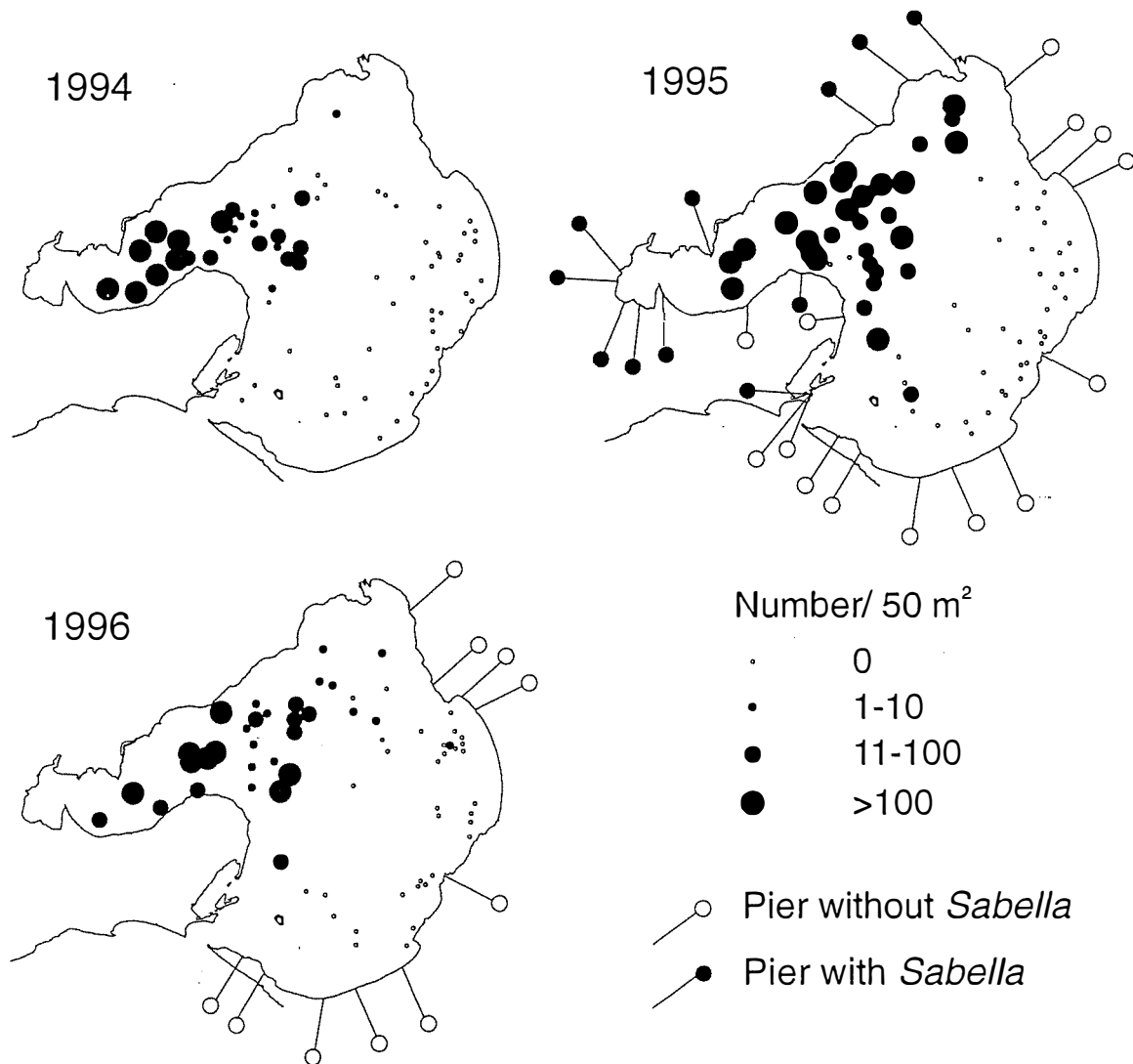


Figure 2 b. The density of *Sabella spallanzanii* based on diver counts on 50 m x 1 m transects sampled between 1994 and 1996, and the locations of piers examined for *S. spallanzanii* in 1995 and 1996.

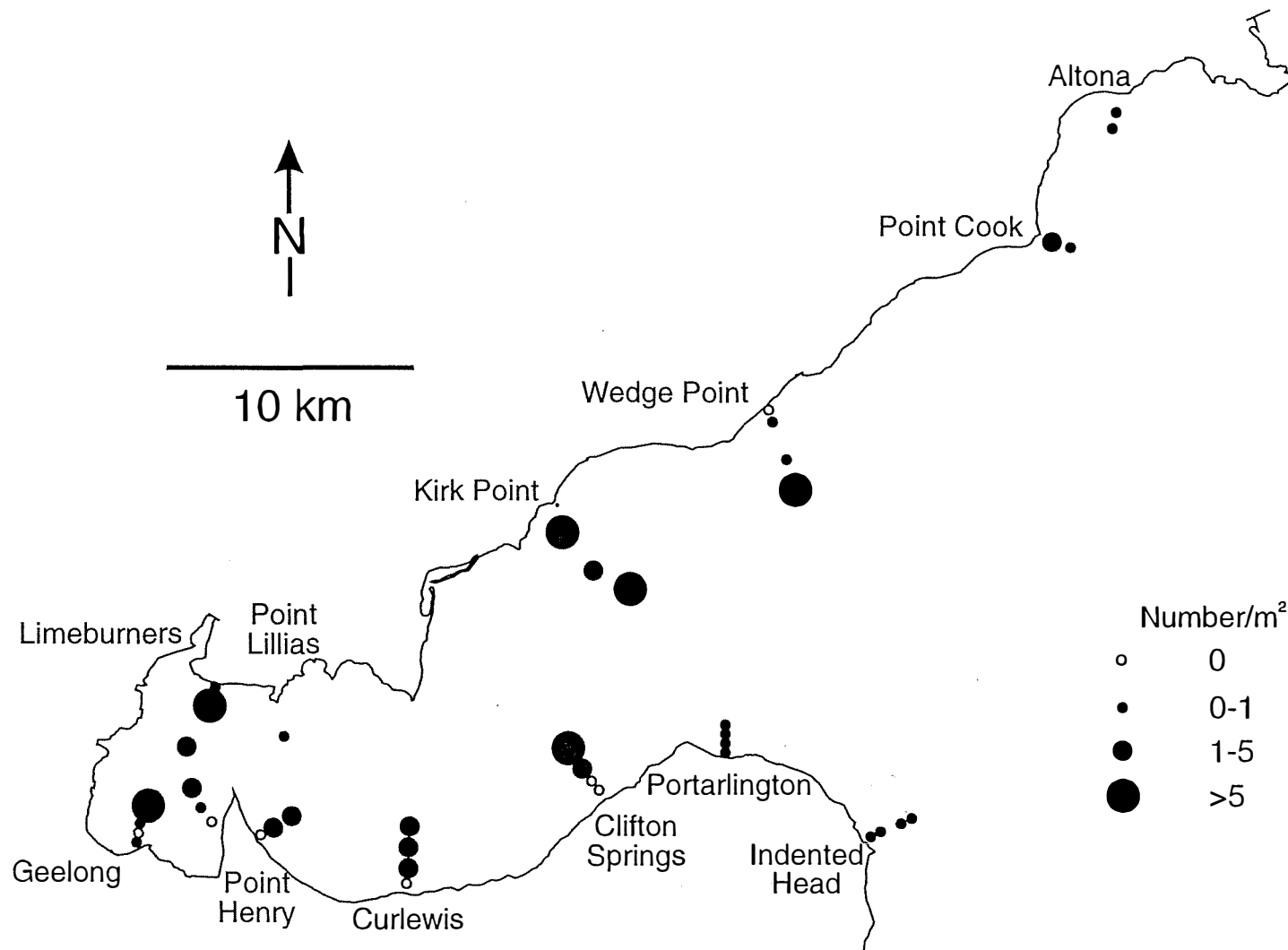


Figure 3. Density of *Sabella spallanzanii* in the Geelong Arm of Port Phillip Bay determined from video transects during 1995.

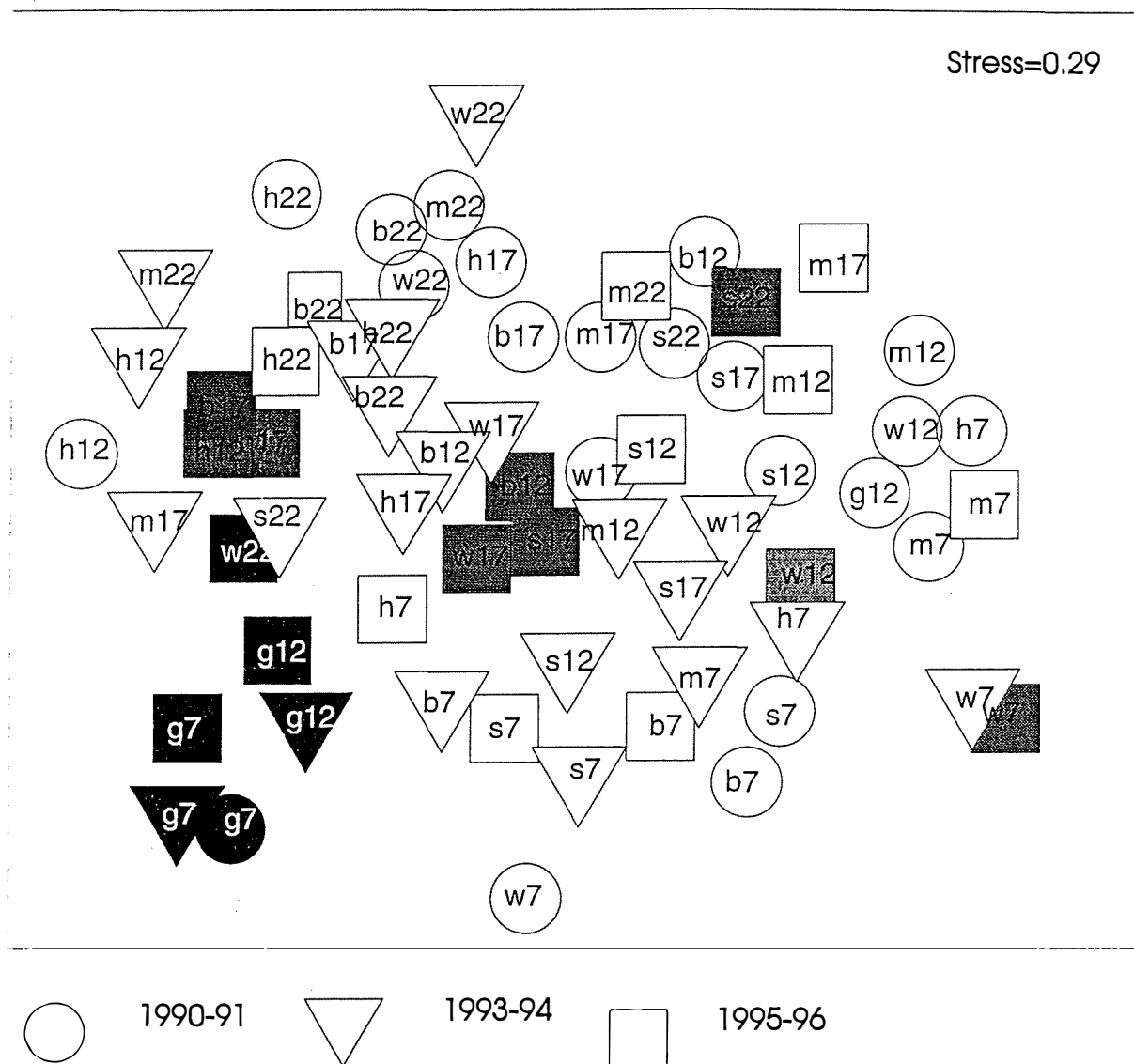


Figure 5. Multidimensional scaling (MDS) plot showing differences in the structure of fish communities between 1990-91, 1993-94 and 1995-96 at 22 stations. Ordinations are based on Bray-Curtis dissimilarities of double square root number. The code for each station is shown and the abundance of *Sabella spallanzanii* at each station is shown by the shading: >50 *S. spallanzanii* (black), 1-50 *S. spallanzanii* (grey) and no *S. spallanzanii* (no shading).

Table 1: Mean densities of *Sabella spallanzanii* (Number/m² ± s.e.) determined by video survey at different depths on transects in the west of Port Phillip Bay (see Fig. 3). Sites containing reef were not surveyed.

Transect	Depth (m)			
	2	4	6	8
Altona	-	-	0.05 ± 0.02	0.41 ± 0.23
Pt. Cook	-	-	2.18 ± 0.16	0.14 ± 0.11
Wedge Point	0	0.90 ± 0.38	0.48 ± 0.10	12.90 ± 3.85
Kirk Point	-	9.34 ± 3.67	1.94 ± 0.76	6.28 ± 1.18
Pt Lillias	-	-	0.30 ± 0.21	-
Limeburners	0.68 ± 0.26	7.86 ± 2.99	2.47 ± 0.82	-
Geelong	0.80 ± 0.11	0	0.79 ± 0.38	7.2 ± 0.71
Pt. Henry West	0	0.79 ± 0.14	1.22 ± 0.23	-
Pt. Henry	0	1.13 ± 0.39	1.72 ± 0.57	-
Curlewis	0	4.61 ± 1.03	3.54 ± 1.56	3.52 ± 0.10
Clifton Springs	0	0	1.65 ± 0.23	11.55 ± 1.70
Portarlinton	0.01 ± 0.01	0.06 ± 0.05	0.13 ± 0.04	0.79 ± 0.42
Indented Head	0.01 ± 0.01	0.52 ± 0.14	0.07 ± 0.07	0.01 ± 0.01
All sites	0.17 ± 0.11	2.52 ± 1.10	1.27 ± 0.30	4.76 ± 1.67

Table 2. The number of *Sabella spallanzanii* attached to different substrates in trawl samples taken at different sites during 1995 and 1996. The percentage of oysters, scallops, and *Pyura stolonifera* which had *S. spallanzanii* attached to them is also shown.

Site / Year	b12 1996	g12 1995	h12 1996	h17 1996	h22 1996	s12 1995	s17 1995	s22 1996	w7 1996	w12 1995	w17 1996	w22 1995	w22 1996	Pt Wilson 1995	Total			
Oyster	0	2	19	8	0	2	10	NR	13	NP	0	NP	2	12	14	NR	NP	82
Oyster shell	4	15						44							6		5	74
Scallop	0	2	0	0	0	0	1	0	0	NP	2	0	5	10	39	NR	0	59
Scallop shell		35								2		2			8		13	60
<i>Pyura stolonifera</i>	NP	36	0	0	NP	NP	NP	1	0	#	3	NP	4	NP	3*	NP	9	56
<i>Herdmania momus</i>								1										1
<i>Anadara trapezia</i>												1					2	3
Bubble weed									150		1	2						153
Sponge										2	1							3
Plastic/rope																	2	2
Unattached	NR	45	60	60	5	0	0	NR	3	~0	NR	100	NR	160	NR	700	11	1144
Oysters % (N)	0(400)	100	31	16	0(2)	14	24	NR	NR	NP	0(2)	NP	100	50	100	NR	NP	.
Scallops % (N)	0(53)	100	0(8)	0(24)	0(27)	0(22)	2	0 (62)	0(22)		2	0(1)	1	7	61	NR	0(3)	.
<i>Pyura</i> % (N)	NP	90	0(2)	0(1)	NP	NP	NP	50	0(12)	NP	50	NP	27	NP	100	NP	90	.

NP Not present, NR Not recorded. * 2 dead # Bubble weed to which *S. spallanzanii* was attached was itself attached to *P. stolonifera* and shell.

Table 3. Analysis of variance table showing significance of changes in abundance of little rock whiting on areas impacted by *Sabella spallanzanii* (g12) and controls (m12, s12) before and after 1992 when *S. spallanzanii* established at g12.

Source of variation	DF	MS	F	<i>p</i>
Effect (Before vs After)	1	3.00783	93.56	0.0001
Area	1	3.85733	119.99	0.0001
Area x Effect	1	2.86545	89.13	0.0001
Year (Effect)	5	0.58382	18.16	0.0001
Area x Year (Effect)	5	0.56445	17.56	0.0001
Area x Effect vs Area x Year (Effect)	1	2.86545	5.08	0.074

Table 4. Diets of 16 species of fish trawled at 5 sites in the Geelong Arm during March 1994 and March 1995.
N = Number of fish analysed. Lav = average length of fish analysed.

Fish	Prey	Percentage of total volume of prey eaten	Percentage of non- empty stomachs containing prey	Average no. of prey in non-empty stomachs
Snapper (N=63, Lav = 97)	Digested fish	26.13	25.40	0.17
	<i>Halicarcinus rostratus</i>	17.00	50.79	1.11
	<i>Trochdota allani</i>	13.31	31.75	0.35
	<i>Diplocirrus</i> sp.1	8.03	19.05	0.19
	Digested matter	6.59	26.98	0.02
	<i>Ophiura kinbergi</i>	5.97	9.52	0.17
	<i>Pontophilus intermedius</i>	3.27	3.17	0.05
	Digested crustacean	2.22	7.94	0.05
	<i>Leptosynapta dolabrifera</i>	2.11	4.76	0.05
	Digested brachyuran	1.91	6.35	0.05
	<i>Aglaja taronga</i>	1.84	1.59	0.03
	<i>Philine angasi</i>	1.46	7.94	0.13
	Digested polychaete	1.18	11.11	0.10
	Digested polynoid sp.	1.13	6.35	0.06
	Digested echiuran	0.84	1.59	0.02
	Digested ophiurid	0.76	9.52	0.10
	<i>Anelassorhynchus porcellus</i>	0.75	1.59	0.02
	<i>Phlyxia intermedia</i>	0.75	1.59	0.02
	<i>Hiatella subulata</i>	0.50	1.59	0.05
	<i>Leucifer</i> sp.1	0.47	11.11	0.33
	<i>Idiosepius notoides</i>	0.42	1.59	0.02
	Digested mollusc	0.35	3.17	0.03
	Digested nereid	0.33	3.17	0.03
	<i>Tenagomysis</i> sp.1	0.33	9.52	0.19
	Digested anthozoan	0.30	1.59	0.02
	<i>Asychis</i> sp.1	0.30	1.59	0.02
	<i>Phyllodoce</i> sp.1	0.30	1.59	0.02
	Green algae	0.25	3.17	
	<i>Glycera cf. americana</i>	0.20	1.59	0.02
	Digested decapod	0.18	9.52	0.17
	Red algae	0.17	1.59	
	<i>Byblis mildura</i>	0.15	1.59	0.02
	<i>Halicarcinus ovatus</i>	0.10	1.59	0.02
	Digested isopod	0.10	1.59	0.02
	<i>Theora cf. lubrica</i> (exotic ?)	0.10	1.59	0.02
	Brown algae	0.08	1.59	
	Digested mysid	0.05	3.17	0.03
	<i>Paradexamine lanacoura</i>	0.03	1.59	0.02
King George whiting (N=56, Lav = 229)	<i>Glycera cf. americana</i>	19.63	14.29	0.16
	<i>Trochdota allani</i>	14.89	58.93	1.18
	Digested fish	13.61	7.14	0.05
	<i>Diplocirrus</i> sp.1	8.90	28.57	0.41
	Echiuran proboscis	8.77	44.64	0.46
	Digested polychaete	5.74	28.57	0.29
	<i>Metabonellia haswelli</i>	4.72	8.93	0.09
	<i>Anelassorhynchus porcellus</i>	3.39	3.57	0.07
	Digested bivalve	3.13	28.57	0.29
	<i>Aglaja taronga</i>	3.03	7.14	0.09
	Digested polynoid sp.	2.49	10.71	0.20
	<i>Theora cf. lubrica</i> (exotic ?)	2.09	3.57	0.18

Table 4 (Cont.)

Fish	Prey	Percentage of total volume of prey eaten	Percentage of non- empty stomachs containing prey	Average no. of prey in non-empty stomachs
King George whiting (cont)	Digested echiuran	1.56	7.14	0.05
	<i>Athanopsis</i> sp.1	0.99	1.79	0.02
	<i>Cymodoce gaimardii</i>	0.95	3.57	0.04
	Digested crustacean	0.85	3.57	0.04
	<i>Philine angasi</i>	0.85	3.57	0.05
	Digested matter	0.80	12.5	0.02
	<i>Leptosynapta dolabrifera</i>	0.69	7.14	0.09
	<i>Pinnotheres hickmani</i>	0.62	1.79	0.02
	Digested brachyuran	0.34	7.14	0.07
	<i>Tellina (Macomona) mariae</i>	0.33	1.79	.
	Digested mollusc	0.28	1.79	0.04
	<i>Harmothoe</i> sp.1	0.27	1.79	0.02
	<i>Liloea brevis</i>	0.25	1.79	0.13
	<i>Natatolana corpulenta</i>	0.16	1.79	0.02
	<i>Artacamella dibranchiata</i>	0.11	1.79	0.02
	<i>Halicarcinus ovatus</i>	0.10	1.79	0.02
	<i>Byblis mildura</i>	0.06	5.36	0.14
	<i>Paraleucothoe novaehollandiae</i>	0.06	1.79	0.02
	Digested <i>Natatolana</i> sp.	0.06	1.79	0.02
	<i>Goniada cf. emerita</i>	0.06	1.79	0.02
	Red algae	0.05	1.79	.
	<i>Halicarcinus rostratus</i>	0.05	3.57	0.04
	Seagrass	0.05	1.79	.
	Green algae	0.03	1.79	.
	Digested ophiurid	0.02	1.79	0.02
	<i>Nebalia</i> sp.1	0.01	1.79	0.02
	<i>Tenagomysis</i> sp.1	0.01	1.79	0.02
Little rock whiting (N=47, Lav = 125)	Digested matter	23.1	57.45	0.02
	<i>Echinocardium cordatum</i>	22.91	44.68	0.47
	Digested mollusc	11.39	27.66	0.06
	<i>Ophiura kinbergi</i>	8.02	10.64	0.36
	<i>Liloea brevis</i>	5.11	19.15	0.4
	Digested gastropod	3.68	19.15	0.21
	<i>Halicarcinus rostratus</i>	3.28	12.77	0.19
	<i>Exosphaemora</i> sp.1	3.21	10.64	0.11
	Digested brachyuran	3.01	14.89	0.15
	Digested polychaete	2.88	17.02	0.11
	Digested ophiurid	2.17	10.64	0.11
	<i>Phlyxia intermedia</i>	2.05	2.13	0.02
	<i>Philine angasi</i>	1.99	2.13	0.02
	<i>Musculista senhousia</i> (exotic)	1.38	4.26	0.06
	Digested fish	1.29	2.13	0.02
	<i>Electroma georgiana</i>	1.24	14.89	0.15
	<i>Trochdota allani</i>	0.95	2.13	0.02
	<i>Philomedid</i> sp.1	0.53	4.26	0.13
	<i>Modiolus inconstans</i>	0.53	8.51	0.17
	Red algae	0.45	8.51	.
	Digested polynoid sp.	0.29	4.26	0.04
	<i>Empoulsenia</i> sp.1	0.14	2.13	0.09
	Digested bivalve	0.14	2.13	.

Table 4 (Cont.)

<i>Ostrea angasi</i>		0.1	4.26	0.02
Fish	Prey	Percentage of total volume of prey eaten	Percentage of non-empty stomachs containing prey	Average no. of prey in non-empty stomachs
Little rock whiting (cont.)	Green algae	0.05	2.13	.
	<i>Nebalia</i> sp.1	0.05	2.13	0.02
	Brown algae	0.02	2.13	.
	<i>Paradexamine lanacoura</i>	0.02	2.13	0.02
	Digested echinoderm	0.02	2.13	.
Eastern shovelnose stingaree (N=39, Lav = 477)	<i>Glycera</i> cf. <i>americana</i>	26.59	48.72	1.77
	<i>Trochdota allani</i>	15.7	76.92	5.00
	<i>Artacamella dibranchiata</i>	12.36	46.15	3.41
	<i>Terebellides</i> sp.1	12.01	23.08	2.62
	Digested polychaete	6.14	41.03	0.36
	<i>Goniada</i> cf. <i>emerita</i>	5.67	43.59	1.18
	<i>Terebellid</i> sp.1	5.03	23.08	1.10
	<i>Leptosynapta dolabrifera</i>	4.70	28.21	1.49
	<i>Anelassorhynchus porcellus</i>	2.41	10.26	0.13
	<i>Diplocirrus</i> sp.1	2.30	46.15	0.82
	Digested matter	1.57	12.82	.
	<i>Leitoscoloplos bifurcatus</i>	1.22	20.51	0.79
	<i>Drilonereis</i> sp.1	0.86	2.56	0.03
	<i>Tharyx</i> sp.1	0.59	15.38	0.33
	<i>Notomastus</i> sp.1	0.41	7.69	0.10
	<i>Metabonellia haswelli</i>	0.38	2.56	0.03
	<i>Abarenicola affinis</i>	0.38	2.56	0.03
	<i>Clymenella</i> sp.1	0.35	5.13	0.05
	Nemertean sp.4	0.26	12.82	0.13
	<i>Harnothoe</i> sp.1	0.21	2.56	0.08
	Digested fish	0.16	2.56	0.03
	<i>Corbula gibba</i> (exotic)	0.15	2.56	0.05
	Monhysterid sp.1	0.14	7.69	0.21
	<i>Lumbrineris</i> cf. <i>latreilli</i>	0.14	15.38	0.23
	Digested polynoid sp.	0.08	7.69	0.08
	<i>Platyeris antipoda</i>	0.08	2.56	0.08
	Digested nereid	0.06	5.13	0.05
	<i>Malmgrenia microscala</i>	0.03	2.56	0.03
	<i>Harnothoe spinosa</i>	0.02	2.56	0.05
Sand flathead (N=20, Lav = 262)	Digested fish	54.23	40.00	0.30
	<i>Gobius</i> sp.1	20.17	5.00	0.05
	Digested mollusc	9.4	15.00	0.10
	Digested brachyuran	4.48	5.00	.
	<i>Philine angasi</i>	2.75	10.00	0.10
	<i>Macrobranchium intermedium</i>	2.18	5.00	0.15
	Digested polychaete	1.71	10.00	0.10
	<i>Philyra undecimspinosa</i>	1.59	5.00	0.05
	<i>Byblis mildura</i>	1.01	5.00	0.80
	Digested matter	0.9	20.00	.
	Digested Leucosiidae	0.75	5.00	0.05
	Echiuran proboscis	0.45	5.00	0.05
	Digested cephalopod	0.15	5.00	.
	<i>Glycera</i> cf. <i>americana</i>	0.11	5.00	0.05
	Digested isopod	0.07	5.00	0.05

Table 4 (Cont.)

		<i>Tenagomysis</i> sp.1	0.04	5.00	0.05	
Fish	Prey	Percentage of total volume of prey eaten	Percentage of non-empty stomachs containing prey	Average no. of prey in non-empty stomachs		
Red mullet (N=18, Lav = 173)	<i>Macrobranchium intermedium</i>	38.89	44.44	0.78		
	Digested fish	14.40	33.33	0.17		
	Digested polynoid sp.	11.51	16.67	0.39		
	<i>Harmothoe spinosa</i>	7.04	11.11	0.44		
	<i>Gobius</i> sp.1	5.80	5.56	0.11		
	Digested matter	5.37	11.11	.		
	Digested polychaete	4.95	11.11	0.17		
	Digested Goby	3.84	11.11	0.17		
	Digested crustacean	2.76	16.67	.		
	Digested Sphaeromid sp.	2.65	5.56	0.22		
	Digested <i>Natatolana</i> sp.	1.67	5.56	0.11		
	<i>Empoelsenia</i> sp.1	0.71	11.11	0.78		
	<i>Amaryllis macrophthalmus</i>	0.17	5.56	0.06		
	<i>Philomedid</i> sp.1	0.08	5.56	0.11		
	Digested <i>Birubius</i> sp.	0.08	5.56	0.06		
	<i>Phoxocephalus kukathus</i>	0.06	5.56	0.06		
Sparsely spotted stingaree (N=14, Lav = 365)	<i>Pontophilus intermedius</i>	23.08	50.00	1.79		
	Digested polychaete	12.74	50.00	0.64		
	<i>Phlyxia intermedia</i>	7.96	35.71	0.86		
	<i>Paralepidonotus ampulliferus</i>	7.81	14.29	0.43		
	<i>Amaryllis macrophthalmus</i>	7.40	28.57	0.71		
	Digested mysid	7.03	50.00	5.64		
	Digested matter	5.38	7.14	.		
	<i>Hippolyte cardina</i>	5.27	14.29	0.43		
	<i>Natatolana corpulenta</i>	4.93	14.29	0.43		
	Digested crustacean	3.44	14.29	.		
	<i>Gobius</i> sp.1	2.69	7.14	0.07		
	<i>Halicarcinus ovatus</i>	2.45	28.57	0.50		
	<i>Siriella vincenti</i>	2.32	50.00	3.86		
	Digested isopod	1.83	7.14	0.21		
	<i>Philyra undecimspinosa</i>	0.77	14.29	0.14		
	Digested <i>Natatolana</i> sp.	0.75	7.14	0.14		
	Digested brachyuran	0.45	14.29	0.07		
	Digested Sphaeromid sp.	0.43	7.14	0.07		
	<i>Halicarcinus rostratus</i>	0.39	7.14	0.07		
	<i>Tenagomysis</i> sp.1	0.39	14.29	0.71		
	<i>Australomysis incisa</i>	0.35	28.57	0.86		
	<i>Paradexamine lanacoura</i>	0.35	28.57	0.29		
	<i>Paranchialina angusta</i>	0.19	14.29	0.36		
	Digested amphipod	0.19	7.14	0.07		
	Digested Leucosiidae	0.19	7.14	0.07		
	<i>Parapandalus leptorhynchus</i>	0.13	7.14	0.14		
	Monhysterid sp.1	0.06	7.14	0.14		
	Digested polynoid sp.	0.03	7.14	.		
	Yank flathead (N=14, Lav = 382)	Digested fish	93.73	85.71	0.93	
		<i>Gobius</i> sp.1	3.74	7.14	0.07	
<i>Litocheira bispinosa</i>		1.79	7.14	0.07		
Digested matter		0.39	7.14	.		
<i>Parapandalus leptorhynchus</i>		0.34	7.14	0.07		

Table 4 (Cont.)

Digested crustacean		0.01	7.14	0.14
Fish	Prey	Percentage of total volume of prey eaten	Percentage of non-empty stomachs containing prey	Average no. of prey in non-empty stomachs
Globefish (N=9, Lav = 197)	<i>Echinocardium cordatum</i>	47.53	44.44	0.44
	<i>Thacanophrys spatulifer</i>	21.18	11.11	0.11
	<i>Corbula gibba</i> (exotic)	20.21	33.33	0.78
	Digested mollusc	5.49	33.33	0.33
	Digested crustacean	3.24	11.11	0.11
	<i>Aglaja taronga</i>	1.62	11.11	0.22
	Digested brachyuran	0.39	11.11	0.11
	<i>Anadara trapezia</i>	0.34	11.11	0.11
Banjo ray (Southern fiddler) (N=5, Lav = 664)	Pilchard	35.52	60.00	0.60
	Digested cephalopod	28.63	20.00	0.20
	<i>Octopus australis</i>	12.49	20.00	0.20
	<i>Gobius</i> sp.1	11.47	40.00	1.20
	<i>Macrobranchium intermedium</i>	4.00	40.00	2.20
	<i>Nectocarcinus integrifrons</i>	3.44	20.00	0.40
	Digested fish	2.19	20.00	0.40
	Digested polychaete	1.56	20.00	0.20
	<i>Pontophilus intermedius</i>	0.39	20.00	0.20
	<i>Sigalion</i> sp.1	0.19	20.00	0.60
	Nemertean sp.1	0.12	20.00	0.20
Greenback flounder (N=5, Lav = 195)	Digested matter	52.61	60.00	
	Digested polychaete	45.57	60.00	0.40
	Red algae	1.82	20.00	
Spiny gurnard (N=3, Lav = 111)	<i>Hemileucon levis</i>	43.90	66.67	9.67
	<i>Dimorphostylis cottoni</i>	32.52	33.33	5.67
	Digested crustacean	16.26	33.33	
	<i>Tenagomysis</i> sp.1	4.88	33.33	0.67
	<i>Empoysenia</i> sp.1	1.63	33.33	0.33
	<i>Philomedid</i> sp.1	0.81	33.33	0.33
Smooth stingray (N=2, Lav = 410)	Pilchard	80.00	100.00	10.00
	<i>Macrobranchium intermedium</i>	17.96	100.00	12.00
	<i>Pinnotheres hickmani</i>	1.80	50.00	0.50
	Digested Sphaeromid sp.	0.24	50.00	0.50
Thornback skate (N=1, L = 340)	<i>Macrobranchium intermedium</i>	100.00	100.00	5.00
Long-snouted flounder (N=1, L = 295)	Prey			
	<i>Ophiocentrus pilosus</i>	100	100	2
Rock flathead (N=1, L = 300)	Stinkfish, common	100		

Table 5. Number of *Sabella spallanzanii* , within and removed from their tubes, and other polychaetes (Fam. Arenicolidae, Nereidae) eaten by King George whiting in laboratory food preference trials.

Feeding trial	Day	<i>Sabella spallanzanii</i>		Other polychaetes	
		within tube	removed from tube	Control 1	Control 2
30 Nov-2 Dec 1995	1	0	0	3	3
	2	0	1	3	3
	3	0	0	3	3
9-12 Dec 1995	1	0	0.5	3	3
	2	0	0	3	3
	3	0	0	3	3
12-15 Dec 1995	1	0	0	3	3
	2	0	0	3	3
	3	0	2	3	3
Total		0	3.5	27	27

Table 6. Heavy metal concentrations ($\mu\text{g/g}$ dry weight) and percentage water in the body and feeding crown of *Sabella spallanzanii*.

	Body	Feeding crown
Arsenic	10.2	11.7
Cadmium	0.03	3.4
Chromium	1.2	62
Copper	2.2	101
Iron	125	5700
Lead	4.6	34
Manganese	10.6	289
Mercury	<0.01	<0.01
Nickel	0.4	25
Vanadium	42	347
Zinc	13	366
Percentage water	67	82.7

APPENDIX 2

**A REVIEW OF LITERATURE ON EXOTIC MARINE INVERTEBRATES
INTRODUCED INTO VICTORIAN WATERS WITH SPECIAL REFERENCE
TO PORT PHILLIP BAY.**

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Technical Report No.

ABSTRACT

Coleman, N¹ and Sinclair M.A.² (1996). A review of literature on exotic marine invertebrates introduced into Victorian waters with special reference to Port Phillip Bay. Mar. Sci. Lab. Tech. Rep.

Twenty two exotic species of marine invertebrates have been recorded from Victorian waters. Eighteen of these are reported from Port Phillip Bay and four are known only from other localities in Victoria. Some of the exotic species recorded from Port Phillip Bay are well established and are present in large numbers, some have been recorded only as isolated individuals and the occurrence of others has been reported but not confirmed.

In this report, literature on the exotic species recorded from Victoria is reviewed, with particular attention being given to those species recorded from Port Phillip Bay. Potential impacts of these introduced species on the local marine fauna are discussed.

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INTRODUCTION.

Twenty two exotic species of invertebrates have been recorded from Victorian waters. Eighteen of these have been reported from Port Phillip Bay and four are known only from other Victorian waters. Some of the eighteen exotics recorded from Port Phillip Bay are well established and are present in large numbers, some have been recorded only as isolated individuals, and the occurrence of others has been reported but not confirmed. This report summarizes information on the biology of these exotic species and discusses their potential impacts on the marine fauna in Victoria.

There are various means by which exotic marine species may be introduced into an area. In some instances, as in the widespread introductions of the Pacific oyster (Quayle 1964; Chew 1979; Sumner 1981), the introductions have been deliberate. These deliberate introductions may also bring with them unintended introductions (eg. Quayle 1964; Bourne, 1979). Species may also be unintentionally introduced by shipping activity, as fouling organisms or in ballast water (Allen 1953; Skerman, 1960a,b; Carlton 1985).

Introduced exotic species may have adverse economic effects or may displace indigenous species or otherwise compromise the integrity of local ecosystems. The economic consequences of introduced exotics may be readily apparent or readily inferred. For example, there are mussel farming and scallop fisheries in Port Phillip Bay. The potential economic impact on these should the North Pacific seastar, *Asterias amurensis*, become established may be readily inferred from the knowledge that it is a voracious predator of shellfish and that it has undergone a massive population explosion since its introduction into Tasmania (McLoughlin and Thresher 1994). Determining the ecological changes due to competition between exotics and native species may be more difficult, particularly if the ecosystems into which the exotics are introduced are poorly known, as is the case for much of Victoria's marine environment.

Port Phillip Bay is the most intensively studied marine system in Victoria. A major environmental study of the bay was carried out from 1968 to 1971 (Melbourne and Metropolitan Board of Works and Fisheries and Wildlife Department of Victoria 1973) and the bay is again the focus of a major environmental study (CSIRO 1992). Most of the exotic species found in Victoria have been recorded from Port Phillip Bay. While the detection of exotic species in the bay is undoubtedly related to the number of studies in the area, the bay is also Victoria's major port and so is probably the area most likely to receive exotic species.

The marine ecosystems of Western Port were studied intensively during 1973-4 (Ministry for Conservation 1975; Smith *et al.* 1975; Coleman *et al.* 1978) but there have been no recent bay-wide assessments of marine invertebrate and plant communities in the bay.

The distributions of some of the commoner intertidal invertebrates along the open coast of Victoria are known (Marine Research Group of Victoria 1984). In contrast, the distributions of subtidal invertebrates and the structure of subtidal communities are virtually unknown, although such data as are available show them to be extremely diverse. Coleman (1996) surveyed the shallow-water (11-50 m depth) benthos in a

small area off the coast of east Gippsland. Not only was the community found to be extremely species rich (803 species from 10.4 m² of sample) but approximately 40 - 50% of the species collected are undescribed. Comparably detailed data for the remaining 1000 km or so of the open coast are not available, but samples taken approximately 80 km to the west of the east Gippsland sites (Coleman unpublished data) contained about 150 species not found in the east Gippsland survey. It seems, therefore, that there are considerable differences in the species composition of subtidal communities even over relatively short distances.

Once an exotic species has been introduced to an area, the further increase in abundance and spread of that species require at least that the environmental conditions in the area are similar to those within the species' natural range. Similarity of environmental conditions is not in itself sufficient to ensure that an exotic will become established. The likelihood of establishment may increase as the number of individuals introduced increases, and if introductions occur on several occasions the likelihood of encountering favourable environmental conditions is increased (Ruesink *et al.* 1995). Certain biological features may also increase the probability that a species will become established outside its natural range. These include high fecundity, high population growth rate, longevity, the ability to occupy a wide range of habitat types, tolerance of a wide range of environmental conditions and high mobility (Ruesink *et al.* 1995). There is also some evidence that colonisation by exotic species is most successful in disturbed or highly modified habitats (Herbold and Moyle 1986; Ruesink *et al.* 1995). Such evidence implies that within Victoria exotic species are more likely to become established in Port Phillip Bay than in the relatively undisturbed communities of the open coast.

The probability that a species will colonise a new area may be assessed by reviewing the literature to determine whether it has invaded other localities (Ruesink *et al.* 1995). If significant ecological impacts occur in one area where an exotic has been introduced, then similar impacts may occur in other areas where it becomes established. If no information on previous invasions is available, data on the ecology of an exotic within its natural range may provide some clue as to its potential impact in other areas. However, species which are ecologically similar in their native ranges may not necessarily behave similarly when they are introduced as exotics. Berman *et al.* (1992) studied the establishment of three exotic species, *Styela clava*, *Botrylloides diegensis* and *Membranipora membranacea*, in the Gulf of Maine. They comment that while these species are ecologically similar and entered similar habitats, they differed in the mechanisms by which they invaded those habitats and in their interactions with native species.

The impact of exotic species may depend on whether they compete with native species for resources or come to occupy some niche which is not otherwise exploited. Nichols *et al.* (1990) describe the displacement of native marine species in San Francisco Bay by the introduced bivalve *Potamocorbula amurensis*. In contrast, Simberloff (quoted in Walker and Valentine 1984) reviewed the literature on species introductions and concluded that in many instances the establishment of introduced species had no effect on communities of native species. Based on this review, Walker and Valentine (1984) calculated that there could be up to 150,000 vacant niches in the marine biosphere. The concept of vacant niches has been criticised because Simberloff equated the failure to

note impacts with the absence of impacts and also failed to consider the possibility of interactions between unrelated taxa (Herbold and Moyle 1986). Nevertheless, there do seem to be cases where exotic species have occupied niches that are vacant or only partially utilised by native species.

The seaweed *Sargassum muticum* Yendo was introduced into British Columbia in association with Pacific oysters. It is now widespread in the Strait of Georgia where it grows in dense stands from low in the intertidal zone to a depth of about 2 m below the low water mark. While the weed is considered a nuisance by fishermen, it appears to occupy a niche not previously dominated by any native species (Bourne 1979). The kelp epiphyte *Membranipora membranacea* has recently become established as an exotic in the Gulf of Maine. Although it is capable of overgrowing native epiphytes, its potential impact has been reduced because it has invaded kelp habitats largely unused by native species (Berman *et al.* 1992). However, kelp fronds encrusted with *M. membranacea* show an increased susceptibility to fracturing during storms. Native species could be indirectly affected if, in the long term, this increased susceptibility results in changes in habitat structure.

The remainder of the present report reviews literature on the distribution, biology and ecology of the exotic species recorded from Victoria. The potential impacts of these exotics on native species are also discussed. Particular emphasis is placed on the exotic species recorded from Port Phillip Bay since it is for this area that most data are available. The report was written by Noel Coleman except for the section on *Carcinus maenas*. This was written by Michael Sinclair who is currently enrolled as a PhD student at Monash University and is studying the ecology of *C. maenas*.

DATA SOURCES

The exotic species currently known from Victoria are listed in Tables 1 and 2. Table 1 (p4) is based on data provided by Dr. Sebastian Rainer, CSIRO Marine Laboratories, Hobart. Many species listed have previously been recorded from Victoria (Hutchings *et al.* 1987; Pollard and Hutchings 1990) but the records for *Euchone* sp., *Musculista senhousia*, *Asterias amurensis*, *Raeta pulchella* and *Pyromaia tuberculata* are new and all have been collected during work carried out by the Victorian Fisheries Research Institute. Table 2 (p5) is based on Hutchings *et al.* (1987) with data on *Tanais dulongi* being provided by Dr. G.C.B. Poore, Museum of Victoria. Table 3 (pp35-38) summarises biological data on exotic species in Port Phillip Bay.

An electronic literature search, for references to the species listed in Tables 1 and 2, was carried out using the *Aquatic Sciences and Fisheries Abstracts* data base. This data base only includes references from 1978 onwards. The Zoological Record for the period 1960 - 1978 was consulted for earlier references. E-mail requests for information were also sent to polychaete and mollusc interest groups.

Asterias amurensis and *Euchone* sp. were omitted from the search. The North Pacific seastar, *Asteria amurensis*, has been omitted because only two individuals have been recorded from the bay and because it is already the subject of intensive research and review as the result of the population explosion of this species that has occurred in

Tasmania (Buttermore *et al.* 1994; Bruce *et al.* 1995). The polychaete *Euchone* sp. is now very abundant in the bay (Currie and Parry 1996 - as *Jasmineira* sp.1) and is a suspected exotic since it was not recorded during the extensive benthic survey that was carried out between 1968 and 1971 (Melbourne and Metropolitan Board of Works and Fisheries and Wildlife Department of Victoria 1973). However, until its specific identity is established it cannot be the subject of a literature search.

Table 1. Exotic species recorded from Port Phillip Bay.

The list is based on data provided by Dr. Sebastain Rainer, CSIRO, Division of Fisheries, Hobart. 1, possible widespread or cosmopolitan species; 2, Species not previously recorded from Victoria in Hutchings *et al.* (1987) or Pollard and Hutchings (1990).

Taxon		Species	
Polychaeta		<i>Boccardia proboscidea</i> <i>Hydroides norvegica</i> ¹ <i>Neanthes succinea</i> ² <i>Pseudopolydora paucibranchiata</i> ¹ <i>Sabella spallanzanii</i> ² <i>Euchone</i> sp. ²	
Mollusca	Gastropoda	<i>Janolus hyalinus</i>	
	Bivalvia	<i>Crassostrea gigas</i> ² <i>Musculista senhousia</i> ² <i>Theora lubrica</i> ^{1,2} <i>Corbula gibba</i> ² <i>Raeta pulchella</i> ²	
Crustacea	Decapoda	<i>Cancer novaezelandiae</i> <i>Carcinus maenas</i> <i>Pyromaia tuberculata</i> ²	
		Echinodermata	<i>Asterias amurensis</i> ²
		Ascidiacea	<i>Molgula manhattensis</i> <i>Styela clava</i>

The exotic species listed for Port Phillip Bay have been identified by taxonomic experts within Australia, in some cases with reference to taxonomists in other countries. The identity of these species has therefore been taken as accurate. A separate project on exotic species is being undertaken by staff at the museum of Victoria. This project includes consideration of taxonomic certainty and should provide further confirmation

(or otherwise) of the identity of these species currently considered as exotic species in Port Phillip Bay.

Table 2. Exotic species recorded only from Victorian waters other than Port Phillip Bay.

The list is based on Hutchings *et al.* (1987). Data on *Tanais dulongi* were provided by Dr. G.C.B. Poore, Museum of Victoria

Taxon		Species	Locality
Mollusca	Gastropoda	<i>Polycera hedgpethi</i>	Eastern Victoria
		<i>Okenia plana</i>	Eastern Victoria
Crustacea	Tanaisiacea	<i>Tanais dulongi</i>	Common along the coast. May be endemic
	Isopoda	<i>Cirolana harfordi</i>	Lorne, western Victoria

PORT PHILLIP BAY

Port Phillip Bay (Fig. 1) is an almost totally landlocked marine bay. The total surface area of the bay is 1950 km². The maximum depth in the middle of the bay is approximately 24 m and about half of the bay is less than 14 m in depth. A few small areas of reef are present, but throughout most of the bay substrata are of sand, silt and clay. Sand predominates around the edges of the bay and silt and clay in the centre. Very little freshwater flows into the bay, the major input being from the Yarra River in the north. The opening to Bass Strait, in the south of the bay, is about 3 km wide. An extensive system of sandbanks and channels in the south of the bay restricts the tidal exchange of water between Bass Strait and the bay. Melbourne, Victoria's largest city and major port is situated at the northern end of the bay and suburbs extend along the eastern and western shores. Geelong, Victoria's second largest city, is situated on the western shore. Sewage from Melbourne is treated at Werribee, between Melbourne and Geelong, and the treated wastewater is discharged into the bay.

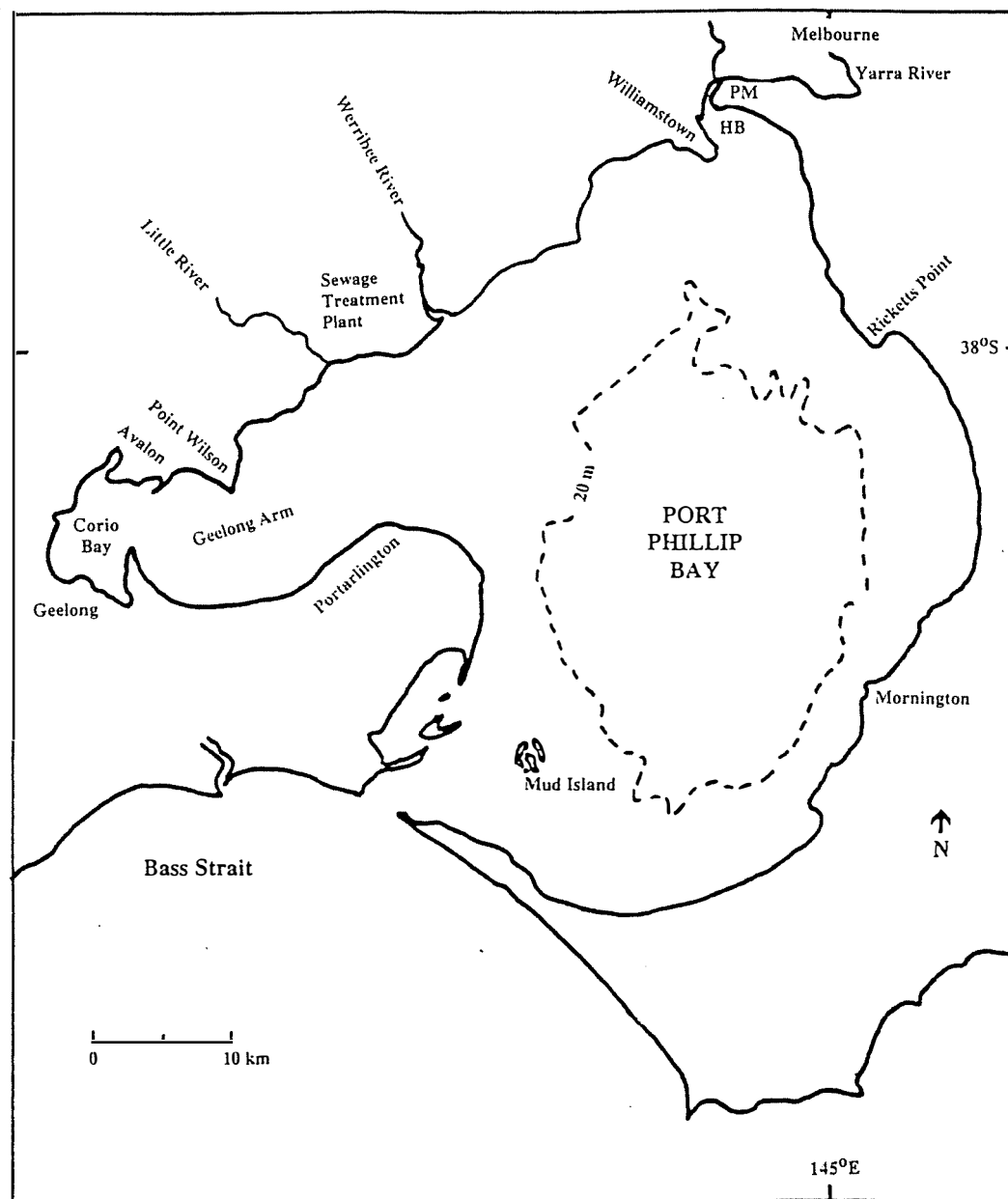


Figure 1. Port Phillip Bay. PM, Port Melbourne; HB, Hobsons Bay. Only localities mentioned in the text are labelled.

REVIEW BY SPECIES

Boccardia proboscidea Hartman, 1940

Description and geographical range

The spionid polychaete *Boccardia proboscidea* was originally described from California, USA (Hartman 1940) and has subsequently been found along the Pacific coasts of North America from Panama to the Bering Sea and in Japan (Imajima and Hartman 1964; Petch 1995). Adults reach a length of 30-35 mm (Woodwick 1963).

Areas and means of introduction

Boccardia proboscidea has been recorded as an exotic species in Western Australia, in South Australia, from Portland, Port Fairy, Warrnambool Apollo Bay, Lorne, Anglesea, Black Rock (near Breamlea) and Gunnamatta Beach along the open coast of Victoria and from Port Phillip Bay (Blake and Kudenov 1978; Hutchings *et al.* 1987; Petch 1995).

Blake and Kudenov (1978) noted that their records of *Boccardia proboscidea* from Port Phillip Bay were the first records of the species in the southern hemisphere. Although these authors made no comment on whether or not *B. proboscidea* was an introduction, Carlton (1985) suggested this to be the case and the most likely mechanisms of dispersal to be via ballast water or as fouling or boring organisms on ships' hulls.

In Port Phillip Bay *Boccardia proboscidea* is present in great abundance in the high intertidal zone adjacent to effluent drains at the Werribee sewage treatment farm. (Dorsey 1982).

Habitat and biology

The species has a wide ecological range. It is an extremely abundant intertidal species and has also been collected in depths up to 100 metres (Hartman 1941; Imajima and Hartman 1964). It has been found burrowing in soft rock, in crevices on exposed rock surfaces, amongst the tubeworm *Galeolaria*, burrowing into gastropod shells and coralline algae, on sandy beaches and intertidal mudflats, amongst barnacles on jetty pilings, in seagrass beds, on algal holdfasts and around sewage outfalls (Woodwick 1963; Imajima and Hartman 1964; Blake and Evans 1973; Dorsey 1982; Petch 1995). Petch (1995) comments that the ecological requirements of *B. proboscidea* in southern Australia appear to be different from its requirements in other areas because most of the southern Australian populations are found near sewage outfalls. However, Dorsey (1981) notes *B. proboscidea* to be an opportunistic species reported from organically enriched areas in other parts of the world and that the habit of tube-building and brooding larvae in tubes (as in *B. proboscidea*) increase tolerance to pollution. *Boccardia proboscidea* withstands salinities ranging from brackish to fully marine, and its occurrence in pools high in the intertidal zone suggests that it is tolerant of

hypersaline conditions and rapid and wide fluctuations in temperature and salinity (Hartman 1941). During mid to high tide periods in those areas of Port Phillip Bay where *B. proboscidea* occurs, the temperature of bottom water ranges from (approximately) 8.5 - 21°C and salinity from (approximately) 21.5 - 34.8‰. The approximate range in air temperature is 0.5°C (winter minimum) to 40°C (summer maximum).

Boccardia proboscidea may feed as a deposit or as a suspension feeder at the sediment/water interface (Taghon *et al.* 1980; Dorsey 1982).

Reproduction is reported to occur during spring in California (Hartman 1941) and during late summer and early autumn in Victoria, Australia (Blake and Kudenov 1981). Egg capsules are deposited in the tubes inhabited by adults. The larvae that develop are of two forms, small larvae which are thought to have a prolonged larval life after they escape from the egg capsule and larger larvae which have a short or no pelagic existence. The possession of two larval types is advantageous for the spread and growth of populations (Blake and Kudenov 1981). Pelagic larvae are dispersed and allow new areas to be colonised, and once successful settlement and growth has occurred the presence of non-pelagic larvae allows a rapid increase in population size.

Considering the wide geographical and ecological range over which *Boccardia proboscidea* is found, there is a possibility that populations referred to as *B. proboscidea* could represent more than one species. However, the adult morphology of *B. proboscidea* is similar throughout its range, giving no indication that more than one species is represented (Petch 1995).

Possible ecological impacts in Port Phillip Bay

The ecological impacts of *Boccardia proboscidea* in Port Phillip Bay are not known although as an abundant species it may compete with native species for food and space. Any impact that it does have is most likely to be in areas already impacted by sewage. It was not recorded from the diets of 35 fish species studied in Port Phillip Bay (Parry *et al.* 1995).

Pseudopolydora paucibranchiata (Okuda, 1937)

Description and geographical range

Pseudopolydora paucibranchiata, a small spionid polychaete, was originally described from Japan (Blake and Woodwick 1975). It also occurs along the Russian coast of the Sea of Japan (Radashevsky 1984). Adults reach a length of 6 - 20 mm (Read 1975; Levin 1981).

Areas and means of introduction

Light (1977) records *Pseudopolydora paucibranchiata* as common in California but does not comment on whether or not it is an introduced species. Levin (1981) does describe it as introduced to California from Japan and gives the length as 15-20 mm.

Read (1975) identified specimens from Wellington Harbor, New Zealand, as *Pseudopolydora cf paucibranchiata* and comments that the Wellington specimens are larger (15 mm in length) than specimens previously recorded (6 mm in length), but gives no discussion as to whether or not the species is introduced.

Within Australia *Pseudopolydora paucibranchiata* has been recorded from Western Australia, from mudflats and seagrass beds in South Australia and from Port Phillip Bay (Blake and Kudenov 1978; Hutchings and Turvey 1984; Pollard and Hutchings 1990).

Blake and Kudenov (1978) suggest that *Pseudopolydora paucibranchiata* is an introduced species, but not the means whereby it could have reached Australia although ballast water transport or as a fouling organism are possible means of dispersal (Carlton 1985). Hutchings *et al.* (1987) suggest that because *P. paucibranchiata* is a small species it could have been transported on oyster shells. However, it seems unlikely that the species reached Port Phillip Bay in this fashion. Japanese (Pacific) oysters have never been introduced into Port Phillip Bay although major importations of Japanese oyster seed were made into Western Australia and Tasmania during 1948-52 and a minor importation was made into South Australia in 1970 (Thomson 1952, 1959; Wolf and Medcoff 1973-4). The only official introduction of Japanese oysters into the natural environment of Victoria was the transfer of oysters from Pittwater (Tasmania) to Mallacoota (in the far east of Victoria) in 1953. These oysters did not become established. Although Pacific oysters have not been introduced into Port Phillip Bay, hatchery reared spat are on-grown in enclosed salt ponds at Avalon on the shores of the bay.

In Port Phillip Bay *Pseudopolydora paucibranchiata* occurs intertidally and subtidally off the Werribee sewage treatment farm. Intertidally *P. paucibranchiata* is present in relatively small numbers (Dorsey 1982). In a study of one outfall drain *P. paucibranchiata* was the dominant species in samples taken offshore with *Capitella capitata* becoming more abundant closer to the outfall (Poore and Kudenov 1978). Other studies also show *Capitella capitata* to occur in heavily polluted areas and *P. paucibranchiata* to be indicative of less affected, semi-healthy areas (Pearson and Rosenberg 1978; Reish *et al.* 1980).

Habitat and biology

Pseudopolydora paucibranchiata is common in sandy-mud sediments in bays and estuaries of California and lives in tubes constructed of fine sand and silt (Blake and Woodwick 1975). Blake and Woodwick (1975) describe the tubes as having multiple openings but Levin (1975) did not find this to be the case. The end of the tube projects above the sediment surface (Levin 1981). *P. paucibranchiata* occurs in areas also occupied by *Boccardia proboscidea* but lower in the intertidal zone. Densities of up to 60,000 individuals per square metre have been recorded, and the distribution of individuals may be controlled by intraspecific aggression (Levin 1975).

Pseudopolydora paucibranchiata tolerates a wide range of temperature and salinity. In the intertidal areas of Port Phillip Bay where *P. paucibranchiata* occurs the temperature of bottom water during mid to high tide periods ranges from

(approximately) 8.5 - 21°C and salinity from (approximately) 21.5 - 34.8‰ (Dorsey 1982).

Pseudopolydora paucibranchiata feeds on organic detritus at the sediment surface and can feed both as a deposit feeder and as a suspension feeder. The species exhibits aggressive behaviour and may fight with other invertebrates, of its own or of other species, for food (Levin 1981).

During reproduction adult females deposit egg capsules on the inside of the tube they inhabit. Myohara (1980) states that oviposition may occur weekly (but does not indicate the total length of the breeding period) and each oviposition produces 7 - 10 capsules each containing 35 - 50 eggs. Radashevsky (1984) states that 15 to 16 capsules each containing 5-50 eggs are deposited, but does not indicate whether this is per oviposition or during the reproductive period.

The species probably has a prolonged breeding period. In California egg capsules have been found in every month of the year and pelagic larvae have been collected every month but January and February, highest numbers occurring from July to October (Blake and Woodwick 1975). Radashevsky (1984) found pelagic larvae from June to October in Peter the Great Bay (Sea of Japan). In Laboratory rearing experiments larvae hatched three or four days after the eggs were laid; metamorphosis began from about two weeks after hatching; and after about 4 weeks 80% of larvae had metamorphosed, 40 - 100% of them were sexually mature and reproduction had begun (Myohara 1980). In the absence of a suitable substratum for settlement, larvae may delay metamorphosis (Radashevsky 1984).

In pollution studies *Pseudopolydora paucibranchiata* has been described as characteristic of semi-healthy areas (Reish 1971; Reish et al. 1980). The habit of tube-building and brooding larvae in tubes, which *P. paucibranchiata* shares with *B. proboscidea*, is associated with tolerance of pollution (Dorsey 1981).

Possible ecological impacts in Port Phillip Bay

The impact of *Pseudopolydora paucibranchiata* on the local marine fauna is not known, though where it occurs in abundance competition with native species for food and space is potentially possible. It has not been recorded from the diets of fish species in Port Phillip Bay (Parry *et al.* 1995).

Sabella spallanzanii (Gmelin, 1791)

Description and geographical range

Sabella spallanzanii is a large, tube building polychaete. The tube is constructed of tough but flexible, semi-transparent material with the outer layer combined with silt or mud and may be up to 40 cm in length (Clapin and Evans 1995). The species is a native of the Mediterranean and of the Atlantic coast of Europe as far north as the English Channel and occurs at depths down to 30 m (Clapin and Evans 1995). It has also been recorded from Rio de Janeiro where it is thought to be an exotic introduction

(Clapin and Evans 1995). Bhatt and Bal (1966) record *Spirographis spallanzanii* from Bombay. They make no comment on whether the species is introduced and give the species distribution as Indo-China, Malay Archipelago, Indian and Atlantic Oceans and Mediterranean Sea. They describe individuals as living in long tubes in the lower littoral zone but give the size as 35 - 50 mm x 2 - 3.5 mm

Areas and Means of introduction

Sabella spallanzanii occurs throughout Cockburn Sound and in harbours at Fremantle, Bunbury and Albany in Western Australia and has also been reported from Adelaide (Clapin and Evans 1995).

Sabella spallanzanii also occurs in Port Phillip Bay. The date of introduction is unknown but was probably within the last 10 - 15 years. It was not collected in the extensive survey of Port Phillip Bay carried out between 1968 and 1971 (Melbourne and Metropolitan Board of Works and Fisheries and Wildlife Department of Victoria 1973) or in a survey of Corio Bay carried out in 1987 (Coleman 1993), but anecdotal information, of large fan worms observed on pier piles during environmental studies, suggest that the worm was established in Corio Bay by 1988 (Mr. A. Stephens, Environment Protection Authority, Victoria personal communication). Provisional identification of worms as *Sabella spallanzanii* were made on specimens collected during trawling in Corio Bay in 1990 (Dr Greg Parry, Victorian Fisheries Research Institute, personal communication).

By 1992 *Sabella spallanzanii* had become the visually dominant organism of the muddy bottom habitat in the Geelong Arm with worms occurring in patchily distributed colonies of 1 to 30 individuals and growing to a height of about 30 cm above the sediment (Carey and Watson 1992). During scallop fishing in 1994, *S. spallanzanii* was found to be extremely abundant throughout the Geelong Arm. The abundance was such that scallop harvesters quickly became clogged with worms (N. Coleman, personal observation). The abundance of the worms decreased towards the east of the Geelong Arm. Within the main body of Port Phillip Bay only small numbers of worms were found, off Portarlington and northwards towards Williamstown. No worms were found in the eastern part of the bay. More details of the distribution and spread of *S. spallanzanii* within Port Phillip Bay are given in Parry (1996).

The means by which *S. spallanzanii* was introduced into Corio Bay is not known. That it is an epifaunal organisms, and has been observed attached to ships, suggests that it could have been introduced as a fouling organism on ships.

Habitat and biology

Although *Sabella spallanzanii* is a common and widely distributed species and has frequently been used in physiological studies, relatively little is known about its biology (Giangrande and Petraroli in press)

In Western Australia *Sabella spallanzanii* appears to be confined to relatively calm waters and is found from just below the water surface to a depths of 30 m. A mean density of 256 m⁻² has been recorded. The base of the tube is usually cemented to a hard substratum such as jetty pylons or shell fragments (Clapin and Evans 1995). The worm may inhabit areas of soft substratum provided there is some solid substratum (eg. shell fragments, pebbles) to which it may attach. In such cases the base of the tube may be partially buried in the substratum. Tubes up to 40 cm in length have been recorded but in older worms increasing age may be accompanied by an increase in weight and an increase in the diameter of the tube rather than by increases in the number of body segments or the length of the tube (Koechlin 1977)

Within its natural range *Sabella spallanzanii* is common along the Italian coast. It occurs in shallow, hard bottom areas of harbours and also in the open sea at depths of 1 - 30 m. Giangrande and Petraroli (in press) suggest that the harbour and open sea forms may be different ecotypes because their behaviour and resistance under laboratory conditions are different. These authors also state that the species is a filter feeder and in the laboratory has been reared on a wide range of food sources, but no details of the diet are given

The growth and reproduction of a population of *Sabella spallanzanii* along an artificial, vertical cliff in the Gulf of Taranto (Ionian Sea) was studied from May 1991 to August 1992 (Giangrande and Petraroli in press). During the study period temperature ranged from 11 - 29°C and salinity was stable at around 38‰.

At the start of the study only small individuals were present and population density was about 300 individuals m⁻². Growth over the following year was rapid with mean tube length increasing from 10 cm in July 1991 to 20 cm in August 1992. During this period population density fell to 150 individuals m⁻².

The minimum size at which sexual maturity occurred was 15 cm (body length). Specimens from 15 - 20 cm were all males with females only occurring in worms greater than 20 cm in body length. The sex ratio for worms 25 - 30 cm long was 1:1.

Gravier (1923 - cited in Clapin and Evans 1995) described *Sabella spallanzanii* as a broadcast spawner. Giangrande and Petraroli (in press) found that in the population they studied gametogenesis begins in summer and spawning occurs in winter (February), but give no comparative information on growth rates and the timing of reproduction for the species in other parts of its range.

Carey and Watson (1992) report that in Corio Bay eggs are released into the water in late summer, which is in contrast to the winter spawning shown by the species in Italy (Giangrande and Petraroli in press) and Clapin and Evans (1995) also found evidence for summer spawning in Western Australia. Small worms, of tube length 8 - 10 cm, have been found in Port Phillip Bay during March (N. Coleman, personal observation), which could indicate a summer spawning. Small worms, of tube length 10-14 cm, have also been found in Port Phillip Bay during late November (N. Coleman, personal observation). Depending on the duration of larval life and the growth rates of newly settled worms in Port Phillip Bay, the presence of juveniles in late November could

indicate an autumn or winter spawning. Such timing would be consistent with the winter spawning reported by Giangrande and Petraroli (in press).

Kiortsis and Moraitou (1965 - cited in Clapin and Evans 1995) found that regeneration in *Sabella spallanzanii* occurred rapidly and that the capacity for head regeneration was high, even after the nerve cord or the intestine had been removed.

Data on a copepod parasitic on *S. spallanzanii* are given in Carton (1968a,b)

Possible ecological impacts in Port Phillip Bay

The ecological impact of *Sabella spallanzanii* on Port Phillip Bay is unknown although the occurrence of the worm in high abundance may increase competition for food and space. There is some evidence that *Sabella spallanzanii* rapidly colonises man-made structures, such as wrecks and pier piles, particularly if new space for attachment is created by physical disturbance (Clapin and Evans 1995; Parry 1996). There is therefore a chance that *S. spallanzanii* could displace some native species if structures become denuded of their epifauna and recolonisation occurs. The fact that *S. spallanzanii* can form large monospecific patches also suggests that the worm may be capable of displacing native species (Clapin and Evans 1995). Although the potential for competition exists, Carey and Watson (1992) state that the worm does not appear to have displaced any indigenous species. They note that tubes of the larger specimens provide a habitat for local species (such as algae, hydroids, gastropods and crustaceans), which might indicate that the presence of the worm allows these species to occur in greater abundance than would otherwise be the case.

Scallop fishers perceive the worm as a considerable threat to their industry. The large numbers of worms collected may reduce the catching efficiency of the scallop harvester, and does increase the time required to sort the catch. There is also concern that the worms, because they are feeding up to 30 - 40 cm above the bottom, may remove food from the water column before it reaches the scallop population. Worms, sometimes several individuals at a time, have been observed attached to the valves of living scallops, although whether this results in any mechanical interference with normal valve activity is not known. There is concern that scallop fishing may aid the spread of the worm around Port Phillip Bay; and because damaged worms are capable of regeneration there are fears that scallop fishing, by breaking-up worms, could actually increase their numbers.

Sabella spallanzanii is not known to have any predators in Port Phillip Bay and did not appear in the diets of 35 species of fish studied (Parry *et al.* 1995; Parry 1996). Studies in Western Australia (Clapin and Evans 1995) did not identify any predators on *S. spallanzanii*, but specimens lacking crowns were observed, which suggests they may be preyed on by some fish species.

Musculista senhousia (Benson, 1842).

Description and geographical range

Musculista senhousia is a small mussel (family Mytilidae) that grows to 2 - 3 cm in length (Willan 1985). The species is native to the western Pacific. The type locality is Chusan, China (Morton 1974), and the species has also been recorded from the coasts of Siberia, South China, East China, the Yellow Sea, the Sea of Japan, Siberia, South Sakhalin, the Kurile Islands and Singapore (Morton 1974; Kulikova, 1978; Slack-Smith and Brearley 1987). Within these areas *M. senhousia* may be a dominant member of the invertebrate fauna by number and by biomass (Kikuchi and Tanaka 1978; Tanaka and Kikuchi 1978; Hayashi 1983; Lee *et al.* 1983) although the species is subject to large fluctuations in abundance (Kikuchi and Tanaka 1978; Tanaka and Kikuchi 1979).

Areas and means of introduction

Musculista senhousia has been introduced into the USA. The first record is from Bolinas Bay in California where it was reported to occur in 1944 (Hanna 1966). Since that date it has spread to San Diego Harbour and has also been found in abundance in Puget Sound, Washington (Willan, 1986). It is thought to have been introduced with shipments of oysters from Japan (Soot-Ryen 1955). The introduction of *Musculista senhousia* to the western Mediterranean coast of France around 1978 is also thought to have been in association with oyster spat from Japan (Hoenselaar and Hoenselaar 1989)

Musculista senhousia occurs in New Zealand and is thought to have been introduced in the late 1970's (Willan 1985, 1987). The first few specimens were collected at about the same time in 1980 from two locations 77 km apart, which suggests either two areas of initial colonisation or, more probably, that the mussel had increased its distribution beyond an initial area colonised prior to 1980. By 1986 the distribution of *M. senhousia* was known to be much more extensive than that indicated by the specimens found in 1980.

Musculista senhousia has been recorded from Western Australia. The first specimens were collected in 1983 and subsequently two small juveniles were identified from samples collected in 1982 (Slack-Smith and Brearly 1987). Collections made between 1983 and 1986 showed the mussel to have spread throughout estuarine sections of the Swan and Canning Rivers (Slack-Smith and Brearly 1987; Willan 1987). Introduction is believed to have been via shipping, either as a fouling organism or in ballast tanks. In the Swan estuary *Musculista senhousia* has colonised soft substrata approximately 0.5 to 4 m below the low water level. Population densities of up to 2,600 mussels m⁻² have been recorded, with the mussels forming dense mats of joined byssal bags. *M. senhousia* have also been observed living epifaunally on boat hulls. High mortality occurs during late autumn and early winter, but it is not known whether this results from the reduced salinity which occurs at this time of year or results from post-reproductive stress.

In Victoria *Musculista senhousia* has been collected at Grantville, Western Port, Victoria (specimens collected by Jack Austin, Malacological Society of Australasia, and seen by N. Coleman) and from Port Phillip Bay.

The first records of *Musculista senhousia* in Port Phillip Bay were made in 1987 when specimens were collected during a benthic survey of Corio Bay (Coleman 1993). This was the first record for Victoria and the first Australian record of the species outside of Western Australia. *M. senhousia* was only collected in small numbers but was found throughout Corio Bay. Empty shell valves are common on beaches around Geelong and mussels have been found cast ashore at Port Melbourne. A small intertidal bed of *M. senhousia* has been reported from Point Wilson north of Geelong (R. Burn, Honorary Associate, Museum of Victoria, personal communication)

The means by which *M. senhousia* was introduced into Victoria is not known but is assumed to be through shipping activity; and as a species capable of living epifaunally by byssal attachment, *M. senhousia* may potentially be spread either as larvae in ballast water or as a fouling organism.

Habitat and biology

Musculista senhousia occurs intertidally; occurs subtidally to depths of at least 20 m, though appears to prefer shallower water; may occur epifaunally on hard, or (semi-) infaunally in soft substrata; and may be found in great abundance with population densities of up to 3,300m⁻² being recorded (Morton 1974; Kikuchi and Tanaka 1978; Slack-Smith and Brearley 1987; Willan 1987). On soft substrata *M. senhousia* may form a nest of byssal threads. The mussel attaches byssal threads to surrounding sand grains forming an anchor. Subsequent byssal threads are wrapped round the shell and attached to sand grains thus forming a nest. The nest appears to serve two functions: as protection for the animal, and to keep sediment out of the mantle cavity (Morton 1974). The mussel does not form nests when it inhabits hard substrata (Morton 1974; Willan 1985).

Where the mussel is abundant on soft substrata, the nests may become joined and form dense mats (Morton 1974; Slack-Smith and Brearley 1987). These mats stabilise the underlying sediment, may trap fine sediment particles and pseudofaeces and may alter the nature of the sediment. Morton (1974) describes the conversion of an area of coarse sand to a mud flat as the result of a dense population of *Musculista senhousia*. Where new areas of soft substrata are densely colonised, the existing infauna may be eliminated because the dense layer of mussels prevents contact with the overlying water (Morton 1974).

The sexes are separate. *Musculista senhousia* is able to spawn at least by the time a shell length of 20 mm has been reached and the eggs are pelagic (Morton 1974 Kikuchi and Tanaka 1978). The timing of spawning and recruitment are variable, presumably depending on location and prevailing environmental conditions. In Lake Naka-umi (Japan) pelagic larvae have been reported to occur from early September to late November; throughout the year, except during midwinter, but particularly during late Autumn; and from June to November. In South Korea pelagic larvae have been reported from early September to late November, and at South Sakhalin larvae are

reported to occur from July to October, with a maximum around August (Kulikova 1978; Kikuchi and Tanaka 1978). In South Sakhalin spawning occurs when the water temperature reaches 15-18°C and is at its maximum, with up to 8,000 larvae m⁻³ of water, when the water temperature reaches its maximum of 20 - 21°C (Kulikova 1978).

Estimates of the duration of pelagic life range from 14 to 25 days (Kulikova 1978; Kikuchi and Tanaka 1978). The larvae prefer to settle on filamentous substrata including seagrass, algae and a wide range of artificial substrata (Kulikova 1978; Willan 1987).

In Hong Kong recruitment occurs by mid January with mussels reaching maturity within the following 6 to 8 months. However growth rate is very variable and mussels spawned in one year grew as much in 9 months as mussels spawned the previous year had grown in 20 months (Morton 1974). In Tomoe Cove (Japan), recruitment to the benthic population occurs between January and April with modal shell length increasing from less than 5 mm during January - April to around 20 mm by the following September (Kikuchi and Tanaka 1978). In Tokyo Bay juvenile mussels have been found to be most abundant in August and September (Kikuchi and Tanaka 1978); and in South Sakhalin settlement is largely completed by September (Kulikova 1978). Life-span is up to about 2 years, though some year classes will vanish well before this age is reached (Morton 1974; Kikuchi and Tanaka 1978; Tanaka and Kikuchi 1979).

Musculista senhousia exhibits a number of features which show it to be an opportunistic species capable of rapidly colonising new habitats (Willan 1987). Fecundity is high, the mussel may settle in dense aggregations (with densities of up to 3,300 m⁻²) and growth is very rapid (adult size may be reached in 9 months). The mussel is fairly flexible in its habitat requirements, being able to colonise either hard or soft substrata and to live epifaunally or infaunally. It tolerates a wide range of salinities. It is reported from brackish water, and salinities down to 18‰ have been recorded from Tomoe Cove where *M. senhousia* is common (Kikuchi and Tanaka 1978; Slack-Smith and Brearley 1987; Willan 1987). *M. senhousia* also tolerates a wide temperature range. In Garolim Bay, Korea, where the mussel is a dominant organism, the average monthly water temperature ranges from 0.8°C to 22°C (Lee *et al.* 1983). *M. senhousia* is not tolerant of anoxic conditions (Tanaka and Kikuchi 1979) or of desiccation, intertidal occurrences being in areas that do not dry out at low tide (Willan 1987).

Willan (1987) comments that the only feature not in accord with opportunism is the limited period of reproduction, although this may vary with environmental conditions. The presence of larvae for much of the year has been reported for Lake Naka-umi in Japan, suggesting that extended reproduction can occur if conditions are suitable (Kikuchi and Tanaka 1978).

Possible ecological impacts in Port Phillip Bay

The ecological relationships of *Musculista senhousia* with native species are not known although there is the potential for competition with local species for food and space. Through its ability to form dense semi-infaunal aggregates bound together by

mats of interwoven byssal nests *M. senhousia* has the ability to change habitat structure and displace native species (Morton 1974). In New Zealand an increase in abundance of *M. senhousia* has apparently reduced numbers of the native mussel *Xenostrobus pulex*, a species which is also common along much of the Victorian coast, and the displacement of a scallop bed by sheets of *M. senhousia* has also been reported (Willan 1987). Kulikova (1978) found spat of *M. senhousia* settled much more abundantly than did those of *Mytilus edulis* on a range of artificial substrata. There is therefore a potential impact on mussel farming in Port Phillip Bay should *M. senhousia* spat settle preferentially over those of *Mytilus*, although no problems in this respect have so far been encountered by the local mussel-farming industry.

Further insight into the potential ecological effects of *Musculista senhousia* as an introduced species may be provided by work being undertaken in the USA. The population biology of *M. senhousia* has recently been studied in Mission Bay, San Diego (Crooks 1992 - not seen by the present author) and its interactions with local species are also under investigation (Crooks, personal communication).

In Western Australia *Musculista senhousia* are preyed on by carnivorous gastropods (Slack-Smith and Brearley 1987) and the same may be true in Port Phillip. *M. senhousia* did not appear in the diets of 35 species of fish studied in Port Phillip Bay (Parry *et al.* 1995) but has subsequently been found in the diets of little rock whiting (*Neoodax balteatus*) (Parry, Victorian Fisheries Research Institute, personal communication).

Theora (Endopleura) lubrica (Gould, 1861)

Description and geographical range

Theora lubrica is a small bivalve (family Semelidae) that grows to about 14 mm in shell length (Tanaka and Kikuchi 1979). The natural range of the species is along the Pacific coast of Asia where it is known from Indonesia, Thailand, China, the Philippines and Japan (Seapy 1974).

Areas and means of introduction

Theora lubrica was recorded from California in the late 1960's and early 1970s (Seapy 1974). The introduction is assumed to be by American naval ships. *T. lubrica* was collected in New Zealand in the early 1970s. Suggested methods of introduction are by transport on prefabricated bridge sections towed from Japan, through dispersal by water currents or through dispersal by shipping (Powell 1976; Climo 1976; Willan 1985).

In Western Australia *Theora lubrica* was first collected in 1971 and was well established in the Swan Estuary by 1974, at which time it was considered to be a recent introduction to the fauna (Chalmer *et al.* 1976). *T. lubrica* was considered as a continuous resident of the Middle Estuary, an area which experiences wide and variable fluctuations in salinity, and to be adapted to estuarine conditions.

Theora lubrica has been present in Port Phillip Bay since at least 1968 when it was collected throughout the bay in great abundance during the Port Phillip Bay Study (Poore and Rainer 1974 - as *Theora fragilis*). *T. lubrica* was the most abundant species (providing 17% of individuals and occurring at 83% of stations) collected in a survey of Corio Bay in 1987 (Coleman 1993).

It is assumed that *Theora lubrica* was introduced into Australia via ballast water (Hutchings et al. 1987). Pollard and Hutchings (1990) comment that *T. lubrica* may occur naturally in Australia and New Zealand. Climo (1976) and Powell (1976) suggested the occurrence of *T. lubrica* in New Zealand was due to natural dispersion by ocean currents, the most probable area of origin being south-east Australia. Willan (1985) argued that while ocean currents have introduced eastern Australian species into New Zealand, the rapid spread of *T. lubrica*, its initial establishment in harbours and its appearance in several countries at about the same time indicate dispersal by shipping.

Habitat and biology

Theora lubrica lives in muddy sediments in bays and is common throughout Japan (Hayashi 1978, 1983; Tanaka and Kikuchi 1979). It was the most abundant species in samples taken in Tomoe Cove, Japan, occurring in silty mud with a temperature range of 11-26°C and with salinity in the overlying water not falling below 18‰ (Kikuchi and Tanaka 1978). *Theora* may occur in great abundance ($>3,700 \text{ m}^{-2}$) but population density shows large seasonal and annual fluctuations (Kikuchi and Tanaka 1978; Tanaka and Kikuchi 1979). The species is a surface deposit feeder (Poore and Rainer 1974).

In Japan recruitment of *Theora lubrica* to benthic populations occurs during all seasons of the year and size-frequency distributions remain relatively similar throughout the year. The species therefore appears to have an extended spawning period and continuous recruitment. Growth (measured on individuals of known size) continues throughout the year. Growth rates are highest at moderate water temperatures (20°C) and are slower both during winter (water temperature 14-15°C) and also when the water temperature reaches maximum summer temperatures (26-27°C). Growth may be very rapid and juveniles of 1 mm shell length can reach adult size of 6 mm in 2 months. Life-span may be up to 2 years, but most individuals die after 1 year (Kikuchi and Tanaka 1978).

Theora lubrica is sensitive to reduced oxygen availability and is considered as a biological indicator species for anoxic conditions (Imabayashi 1988). Population density decreases as oxygen concentration in the bottom water decreases. This relationship is shown in two ways: at any one time the distribution and abundance of *T. lubrica* may be related to oxygen concentration in the overlying water; and over a period of time the population in an area may become extinct (below 1-2 ml O₂/l) or show a drastic reduction in numbers in relation to seasonal (or random) reductions in oxygen availability (Imabayashi 1983, 1986; Tanaka and Kikuchi 1979). Large individuals are more tolerant of anoxic conditions than small ones are; and because *T. lubrica* has an extended period of spawning and recruitment, and rapid growth,

populations may quickly recover once the period of anoxia is past, provided a few individuals survive or there are populations in adjacent areas.

Possible ecological impacts in Port Phillip Bay

The population dynamics of *Theora lubrica* have not been studied in Port Phillip Bay, nor is its impact, if any, on native species known. Kikuchi and Tanaka (1978) described the growth rate of *Theora* as being most rapid at about 20°C. Water temperatures in Port Phillip Bay range from about 9 -- 24°C and average temperatures are 18+°C for at least five months (Cowdell et al. 1984; A. Longmore, Victorian Fisheries Research Institute, personal communication), from which it may be inferred that conditions probably favour rapid growth for several months of the year. *T. lubrica* has been recorded as a minor component of the diets of greenback flounder and red gurnard in Port Phillip Bay (Parry et al. 1995).

Corbula gibba (Olivi, 1792)

Description and geographical range

Corbula gibba is a small bivalve which grows to a maximum size of about 1.6 cm in shell length (Hrs-Brenko 1981). A particular characteristic of the species is that the shell is markedly asymmetrical, the right valve being much larger than and overhanging the left (Yonge 1946). Its natural range is from Norway to the Mediterranean.

Areas and means of introduction

Port Phillip Bay appears to be the only area in which *Corbula gibba* has been recorded as an introduced species. It was not recorded from Port Phillip Bay prior to 1974 (Poore and Rainer 1974) but was found in Corio Bay in small numbers during 1987 (Coleman 1993 - recorded as *Corbula* cf *flindersi* but not referred to specifically in the survey report). Samples taken off St. Leonards in 1991 showed that *C. gibba* (as *Corbula* cf *coxi*) was present at densities of up to 100 per 0.1m⁻² (Currie and Parry 1995). Observations made (by N. Coleman) on board commercial scallop boats over the last 2-3 years have shown that *C. gibba* is abundant throughout Port Phillip Bay and is frequently collected in association with scallops (*Pecten fumatus*).

Habitat and biology

Corbula gibba occurs from the shallow sublittoral zone to depth of around 140 m. It inhabits thick muddy sand containing gravel and small stones and may be present in great abundance. Numbers retained on a 1 mm sieve from samples in the Limfjord, Denmark, indicate population densities of up to 53,000 m⁻² (Jensen 1988, 1990). The species is a shallow burrower. It lives infaunally in the mud and attaches itself by a single byssus thread to a piece of gravel or stone. In contrast with most sand- and mud-dwelling bivalves *C. gibba* is relatively immobile and leads a sedentary life (Yonge 1946).

Corbula gibba is a suspension feeder. The inhalant siphon, through which water and food are drawn into the mantle cavity, lies flush with the surface of the substratum. Water is drawn in from the sediment-water interface and so contains much bottom material, including bottom-living diatom, bacteria and organic debris (Yonge 1946). The water above soft, muddy substrata tends to be relatively turbid with a high proportion of re-suspended organic and inorganic material. *C. gibba* has a number of structural, behavioural and physiological adaptations for feeding under such conditions and is also capable, to a relatively high degree, of preferentially ingesting organic particles (Yonge 1946; Kiørboe and Møhlenberg 1981)

The sexes are separate. Spawning occurs mainly in late summer and autumn, (from August to November in the northern hemisphere) but larvae have also been found in the plankton in winter and spring (Yonge 1946; Hrs-Brenko 1981). Jones (1956) states that larvae of *C. gibba* have a long pelagic life, but gives no estimate of the duration. Settlement of spat has been reported for all seasons of the year and densities of up to 67000 m⁻² have been recorded, although mortality may be very high (80%+) in the months following settlement (Jones 1956; Muus 1973; Jensen 1988).

The longevity of *Corbula gibba* has been estimated at 4 - 6 years (Jones 1956; Jensen 1988). Growth occurs from spring to early autumn. Growth rates are very variable but *C. gibba* may reach 5 - 7 mm shell length in the year after settlement (Jones 1956; Jensen 1988, 1990). During the course of this century eutrophication has increased in the Limfjord. *C. gibba* appears to have responded to the increase in organic load by increasing its growth rate, but also shows a decreased lifespan, which is now estimated to be only 2 years (Jensen 1990). The production of *C. gibba* in the Limfjord is also very high, and the P/B ratio is amongst the highest recorded (Jensen 1990).

Little is known about predators of *Corbula gibba*. Jones (1956) found that few fish species eat adult specimens, probably because of the thick shell, although empty shells with holes drilled by predatory gastropods were found. Newly settled spat are probably much more susceptible to predation, and this may explain the large decrease in abundance that occurs after settlement (Jensen 1988)

Corbula gibba occurs at salinities of 27-33‰; at temperatures of -1 to 16°C; and at oxygen concentrations of 7-11 mg/l. (Jensen 1988, 1990). *C. gibba* can also withstand very low oxygen concentrations. In laboratory experiments individuals have survived for 57 days under almost anoxic conditions (0.18 - 0.37 mg oxygen/l) and in the field have been collected from areas with an oxygen concentration of 0.97 ml/l (Zarkanellas 1979; Jensen 1990). Because *C. gibba* tolerates eutrophic conditions and low oxygen levels it will survive in conditions where many other species are eliminated. It is often a characteristic species in polluted areas, is found at the edge of anoxic and azoic zones and is a pioneer species in the recovery of areas whose fauna has been destroyed by pollution (Pearson and Rosenberg 1978; Zarkanellas 1979; Rygg 1985; Crema *et al.* 1991).

Possible ecological impacts in Port Phillip Bay

The impact of *Corbula gibba* on the marine communities of Port Phillip Bay is not known. *C. gibba* is widespread, may be present in large numbers, and is specialised for

feeding at the sediment-water interface. It may compete for food with local species that exploit the same resource. Of particular concern is the possibility of competition between *C. gibba* and scallops.

Corbula gibba has been found in the diets of 9 species of fish (out of a total of 35 species) studied in Port Phillip Bay (Parry *et al.* 1995). Over the depth range 7 - 22 m the importance of *C. gibba* in the diet tended to increase as the depth of water from which the fish were taken increased. For most species the incidence of *C. gibba* in the diet was low (<5% by volume) but it was the most important item in the diet of globefish (contributing 57% by volume to the diets of fish taken from deeper stations) and was the fourth most important item in the diet of Elephant shark (contributing 20% by volume to the diets of fish from stations in the middle of the depth range).

In Port Phillip Bay shells drilled by predatory molluscs have occasionally been found. Shells containing up to six incompletely drilled holes are not uncommon, suggesting that the shell of this species is frequently too thick to be successfully penetrated by local predatory molluscs (G. Parry, Victorian Fisheries Research Institute, personal observation).

During a study of the effects of scallop dredging, mortality rates for *Corbula gibba* (66%) were considerably higher than the rates (typically 20 - 30%) for other infaunal species (Currie *et al.* 1996).

Pyromaia tuberculata (Lockington, 1877)

Pyromaia tuberculata is majid crab which typically grows to a carapace length of 16 - 27 mm (Garth 1958; Sakai 1976; Morgan 1990). It occurs naturally in the eastern Pacific from Tomales Bay, California, USA southwards, including the Gulf of California, Costa Rica, Bay of Panama and Colombia (Garth 1958). Two or three races, restricted to well-defined portions of the species' geographical range, may be recognised (Garth 1958).

Areas and means of introduction

Pyromaia tuberculata has been introduced into Japan and into New Zealand (Sakai 1976; Webber and Wear 1981). The species was first collected in Japan in 1970 although specimens were numerous by that time (Sakai 1976) and so the species may have been introduced and become established prior to that date. Specimens (provisionally identified as *P. tuberculata*) were collected in New Zealand in 1978

The species was identified from Western Australia in 1990, but the specimens on which the identification was based had been collected in 1978 (Morgan 1990).

Pyromaia tuberculata has been recorded from Port Phillip Bay where it appears to be well established (Parry *et al.* 1995). The date of introduction to the bay is not known, but the fact that it appears to be well established coupled with the knowledge that it was not recognised in Western Australia until 12 years after it became established (Morgan 1990) suggest that it could have been present for several years.

The introduction of *Pyromaia tuberculata* to new areas is probably through the ballast-water transport of larvae (Sakai 1976; Morgan 1990).

Habitat and biology

Pyromaia tuberculata occurs from low in the intertidal zone to a depth of 225 fathoms. It is found on soft substrata ranging from soft mud containing shell gravel to firm sand, is found amongst rocks and is found amongst seaweed and tunicates on wharf pilings. It may cover itself with foreign growth. (Garth 1958).

In the Americas ovigerous females have been found during most of the year. The frequency of ovigerous females shows a slight increase in the summer months in southern California and during spring (March) in the Gulf of California (Garth 1958). In New Zealand, where the species has been introduced, ovigerous females have been found from April to August (Webber and Wear 1981). While these are the same months as those during which ovigerous females may be most frequent in the northern hemisphere, in the southern hemisphere they are autumn and winter (rather than spring and summer) months.

Possible ecological impacts in Port Phillip Bay

No quantitative data on the distribution, abundance and ecology of *Pyromaia tuberculata* in the bay are available. It has been recorded from the diets of 8 species of fish (sand flathead, sparsely-spotted stingaree, globefish, snapper, banjo ray, red mullet, elephant shark and spiny gurnard) and was consumed by fish over the entire depth range (7 - 22 m) sampled (Parry et al. 1995).

Carcinus maenas (Linnaeus, 1758)

Description and geographical range

The European shore crab, *Carcinus maenas* (family Portunidae) reaches 86 mm in carapace width (CW) (Crothers 1966a) and is also known as the green crab and as Joe Rocker.

Carcinus maenas is native to European waters. It is reported from Iceland, Faroes Island and Shetland Island (Feder and Pearson 1988), and is widespread around the United Kingdom (Crothers 1970a; Elner 1978; Ameyaw-Akumfi and Naylor 1987; Ash 1989). *C. maenas* is present from the North Sea to the Arctic limits (Chilton 1910) and around the North Cape (Feder and Pearson 1988). It has been studied in Norway (van der Meeren 1994), Sweden (Pihl and Rosenberg 1982), Denmark (Munch-Peterson *et al.* 1982), Holland (Beukema 1991) and France (le Calvez 1987). *C. maenas* is also present around Portugal (Queiroga *et al.* 1994) and in the Mediterranean and Black Seas (Chilton 1910).

Areas and means of introduction

Carcinus maenas has been reported from northern Africa and the Suez Canal (Feder and Pearson 1988), the Red Sea (Chilton 1910), Cape Peninsula (le Roux *et al.* 1990), Cape Town and Madagascar (Joska and Branch 1986). *C. maenas* is present around India (Chilton 1910), Ceylon (Joska and Branch 1986) and Burma (Boschma 1972). In North America, it is found around Nova Scotia and Maine (Welch 1968; Thomas and Himmelman 1988), New England (Welch 1968), New Jersey (Feder and Pearson 1988) and Virginia (Joska and Branch 1986). *C. maenas* is also found on the eastern coast of northern America at Willapa Bay (Joska and Branch 1986) and California (Cohen *et al.* 1995; Grosholz and Ruiz 1995). It has also been reported from Hawaii (Chilton 1910). In South America, *C. maenas* has been recorded from Panama and Brazil (Chilton 1910).

Introduction to Australia

Day and Hutchings (1984) tentatively reported *C. maenas* from Merimbula, and more recently Hutchings *et al.* (1989) found it at Narooma and Twofold Bay, New South Wales. *C. maenas* is present around the Adelaide area (Hallett Cove, Port Stanvac, Outer Harbour and West Lakes) (Rosenzweig 1984) and along the Coorong (Zeidler 1988). A single specimen has been reported from the Swan River, Perth (Zeidler 1978), but whether a successful population has become established is unknown. *C. maenas* is well established along the coast of Tasmania (R. Thresher, pers. comm. 1995).

Introduction to Port Phillip Bay and Victoria

Carcinus maenas was first recorded in Port Phillip Bay by Fulton and Grant (1900). They remarked that it was “plentifully distributed” from Frankston to Portarlington. They also reported that previous studies in 1855 and 1882 had failed to find *C. maenas*. Thus, *C. maenas* was probably introduced to coastal waters of southern Australia sometime after 1882.

The distribution of *C. maenas* around the Victorian coastline is depicted by Marine Research Group of Victoria (1984). From their map, *C. maenas* is present in Port Phillip and Westernport Bays (including French Island), and around Lorne, Wonthaggi, Venus Bay, Cape Liptrap, Waratah Bay, Wilson’s Promontory, Corner Inlet, Port Welshpool, Port Albert, Lakes Entrance, Lake Tyers, Cape Conran and Mallacoota.

Probable means of transport to establish exotic populations

Carcinus maenas was most likely introduced as a consequence of shipping activities – either within fouling communities on ships’ hulls or in the ballast water of ships (Zeidler 1988). Joska and Branch (1986) stated that oil rigs, with their underwater structures, not ships, were most likely responsible for the introduction of *C. maenas* to South Africa.

Habitat

Crothers (1970b) and Joska and Branch (1986) stated that *C. maenas* prefers sheltered shores, not exposed coasts. Joska and Branch (1986) proposed that the range expansion of *C. maenas* may be reduced across exposed coastlines. *C. maenas* spread

1500 km along the east coast of northern America in 100 years, whereas it took 80 years to spread 500 km in south-eastern Australia – a difference in the amount of exposed coastline may explain the different rates of range expansion.

Carcinus maenas has been studied in a wide range of intertidal habitats. For instance, in Europe, *C. maenas* has been studied in an intertidal creek of an estuarine brackish marsh (Cattrijsse *et al.* 1994), mud and sand areas (Crothers 1970a; Klein Breteler 1976a; Munch-Peterson *et al.* 1982; le Calvez 1987; Günther 1990; Beukema 1991), organically enriched sediments (Feder and Pearson 1988), seagrass meadows (Pihl Baden and Pihl 1984), rocky shores (Crothers 1970b) and mussel beds (Klein Breteler 1976b).

Outside Europe, *C. maenas* has been studied on sand and shingle beaches and rocky intertidal shores in Maine (Berrill 1982; Berrill and Arsenault 1982), in lagoons and stream mouths in California (Cohen *et al.* 1995), in the docklands of South Africa (Joska and Branch 1986) and in sandy mud habitats of south-eastern Australia (Day and Hutchings 1984).

Carcinus maenas is an intertidal and subtidal species, migrating on and off the shore with high tides (Naylor 1962). Little is reported of the subtidal habitats where *C. maenas* occurs. Crothers (1970a) reported that most *C. maenas* are limited to 5.5 m water depth, but this may be confounded with distance from shore; Rasmussen (1959) reported that 8–10 m is the maximum depth at which *C. maenas* is found.

A survey of the gut contents of fish trawled at 22 sites at depths of 7, 12, 17 and 22 m in Port Phillip Bay during 1994 (n>30 species, n>6000 fish, Parry *et al.* 1995; Officer and Parry 1996) failed to find any *C. maenas*. In contrast, *Nectocarcinus integrifrons*, a local crab species, was commonly found in this survey, suggesting that *C. maenas* may be confined to depths shallower than 7 m in Port Phillip Bay by *N. integrifrons* (G. Parry, VFRI, pers. comm. 1996).

Temperature range

Atkinson and Parsons (1973) and Naylor (1965a) reported that water temperatures rise from about 4°C in winter to about 18°C in summer in Wales. In the Dutch Wadden Sea, water temperatures range from 3°C in winter to 18°C in summer on average, but can fall below 1°C in some winters (Beukema 1991). Eriksson and Edlund (1977) reported that water temperatures range from –0.3 to 19.7°C in Sweden.

Berrill (1982) reported that water temperatures in Maine are below 7°C from November to April and above 10°C for five months. Water temperatures around Port Phillip Heads, Victoria, Australia, range from 12°C in winter to about 20°C in summer (King 1970).

Salinity range

Crothers (1966a) stated that adult *C. maenas* could survive in salinities ranging from 10 to 33 ppt and as low as 4 ppt in Wales. In Portugal, *C. maenas* is most abundant in salinities of 20–28 ppt (Marques and Costa 1984). *C. maenas* is found in Swedish waters that average 25 ppt (Eriksson and Edlund 1977).

Carcinus maenas survived salinity cycles of 5–30 ppt in laboratory conditions (Bolt and Naylor 1985). Ameyaw-Akumfi and Naylor (1987) found that *C. maenas*, in the laboratory, has a lower salinity preference of 27 ppt. McGaw and Naylor (1992) conducted salinity preference experiments on *C. maenas*, with salinities ranging from 5 to 50 ppt, and found that crabs of different intermoult length have different salinity preferences, and that crabs could discriminate between salinities differing by 0.5 ppt.

General Biology

Larval stages

Following fertilisation, eggs are carried by females for four months in warmer waters to most of the year in colder waters (Crothers 1966a). Eggs hatch in late spring to early summer (Crothers 1966a). Broekhuysen (1936) noted that short drops in temperature could kill high proportions of eggs, and Wheatly (1981) found that, at temperatures exceeding 25°C, egg mortality increased, despite behaviour by females to improve oxygenation to eggs. Crothers (1966a) reported that eggs developed normally at 10°C if salinity exceeded 26 ppt, but at lower temperatures, higher salinities were required for successful development.

Prezoeae hatch from eggs and are released in deeper water (Rasmussen 1959); within a few hours, prezoeae moult into the first of four zoeal stages (Crothers 1966a) [see Rice and Ingle (1975) and Noone (1987) for illustrations of zoeae]. The duration of larval development is inversely related to temperature (Dawirs 1985). The fourth zoeal stage moults into the megalopal stage – megalopae appear in early–mid summer and, over suitable habitat, moult into the first crab stage in late summer (Crothers 1966a). Queiroga *et al.* (1994) found that prezoeae are most abundant on nocturnal ebb tides, whereas megalopae are most abundant on nocturnal flood tides. Klein Breteler (1975a) measured the first crab stage at 1.5 mm CW.

Combined effects of temperature and salinity on zoeal development under laboratory conditions were studied by Nagaraj (1993), who found that lower water temperatures (e.g. 10°C compared with 25°C) and higher salinities (e.g. 30 and 35 ppt compared with 20 and 25 ppt) result in the highest survival rates of zoeae.

Moulting

The number of moults from settling to terminal anecdyosis was estimated at around 18 by Crothers (1966a). Hogarth's (1975) equation, relating carapace width to moult number, suggests that crabs moult 20 times before terminal anecdyosis. Klein Breteler (1975b) found that increased temperatures accelerated the moulting cycle; he reported that various authors had estimated the relative increase in carapace width at 20–50%. Carapace width of female crabs increases at a faster rate than that of males over the first nine crab stages (Shen 1935). The puberty moult of females is attained after 11–12 moults (Mohamedeen and Hartnoll 1989). Carlisle (1957) reported that *C. maenas* moults at all times of the year, except during the coldest part of winter. Growth, according to Eriksson and Edlund (1977) and Berrill (1982), appears to be suppressed at temperatures below 10°C.

Maturity

Size at maturity varies between seasons – Crothers (1966a) reported that females first reach maturity at 16–23 mm CW in spring or at 23–31 mm CW in summer. Size at maturity also varies with water temperature – for warmer waters, females reach maturity at 16–30 mm CW, and in colder waters at 34–45 mm CW (Berrill 1982). Males reach maturity at 25–30 mm CW (Crothers 1966a) – no seasonal or temperature variation has been reported. The smallest ovigerous female found in Victorian waters (Australia) was 32.3 mm CW (M. Sinclair, unpubl. data).

Breeding

Males carry females from a few days before females are due to moult until a few days after copulation (Crothers 1966a; Berrill and Arsenault 1982). It has been suggested that premoult females release sex pheromones attracting males (Eales 1974). Aggressive interactions may occur between males for females (Reid *et al.* 1994) during the breeding season, which occurs over summer (Crothers 1966a). Following copulation, 200 000 eggs [as suggested by Joska and Branch (1986) for an average-sized female] are carried by the female. Rasmussen (1959) and Crothers (1966a) reported that ovigerous females move offshore, where they remain until their eggs hatch. Ovigerous females are common in winter, although some ovigerous females carry eggs in summer (Crothers 1966a). Naylor (1965b) described an upper temperature barrier where breeding is prevented in waters of 14–28°C.

Udekem d'Acoz (1993) suggested that larger females may breed two or three times per year and smaller females may breed only once; however, Marques and Costa (1984) reported that *C. maenas* could breed throughout the year with each female reproducing only once. Van der Meeren (1994) reported that females congregate in hot spots for mating and that mating success is size dependent.

Crothers (1966a) suggested that variation in timing of breeding season that occurs between sites may reflect differences in water temperatures. Around the United Kingdom, copulation occurs from July to September, and ovigerous females can be found from January to April (Crothers 1966a). In Portugal, copulation occurs from April to May and September to December, and ovigerous females are present from October to June, peaking in January and February (Almaça 1982). In Belgium, *C. maenas* copulates from April to November, but mainly from June to October, and ovigerous females occur from December to August (Udekem d'Acoz 1993).

In Maine, copulation peaks in August and presence of ovigerous females peaks from May to June (Berrill 1982). Joska and Branch (1986) reported that ovigerous females in South Africa occur from June to December. In Victoria, Australia, copulation occurs from September to March, peaking in February–March (M. Sinclair, unpubl. data).

Larval duration and settlement preferences

Wear (1974) reported that incubation time of *C. maenas* is temperature dependent – at 10°C development takes approximately 75 days, and at 25°C development takes around 13 days.

Thiel and Darnedde (1994) reported that mussel clumps were important refuges for juvenile crabs. Klein Breteler (1975a) found juvenile crabs over tidal flats. Settlement of juvenile crabs may be enhanced by highly variable carapace patterns: these patterns may have a cryptic function, reducing visual predation (Hogarth 1978).

Movement

Declines in the abundance of intertidal *C. maenas* occur during the overwintering period when crabs migrate offshore (Edwards 1958; Atkinson and Parsons 1973; Klein Breteler 1976a). Naylor (1958) reported that *C. maenas*, in the laboratory, is active during perceived high tides and hours of darkness. Naylor (1962) and Hunter and Naylor (1993) documented migration of crabs in the field. However, smaller crabs tend to remain in the intertidal zone, whereas larger crabs migrate with the tide (Warman *et al.* 1993). In Victoria, a decrease in abundance of intertidal *C. maenas* occurs from June to September–October (M. Sinclair, unpubl. data).

Diet and feeding mode

Carcinus maenas has a broad diet including annelids, bivalves, gastropods and limpets, amphipods, barnacles, crabs and isopods, fish and algae (Ropes 1968; Elner 1981; Feder and Pearson 1988; le Roux *et al.* 1990). Feder and Pearson (1988) concluded that *C. maenas* feed intensively with 55% of stomachs at least half full. Ropes (1968) suggested that feeding may be suppressed at temperatures below 7°C. Hawden (1993) reported that *C. maenas* from Mornington, Ricketts Point and Mud Island in Victoria consumed native crabs, bivalves, gastropods, isopods, polychaetes, amphipods and algae. In the laboratory, Hawden (1993) also found that *C. maenas* consumed two native crabs species – *Paragrapsus gaimardii* and *P. quadridentatus*.

Carcinus maenas crushes small mussels and bores through large mussels, but prefers small mussels because handling time is reduced (Ameyaw-Akumfi and Hughes 1987). Auster and Crockett (1984) reported that *C. maenas* excavates soft sediments for prey. Consumption of prey by *C. maenas* is increased at higher temperatures (Elner 1980; Sanchez-Salazar *et al.* 1987). Jensen and Jensen (1985) proposed that juvenile *C. maenas* structure benthic communities in Denmark, by preventing cobble-bed development.

Parasites, predators and other factors that control abundance

Carcinus maenas has a number of predators including octopus, fish, birds, foxes, rats, and humans. Adult bass, in waters of the United Kingdom, feed mainly on *C. maenas* (Kelley 1987). Darnedde (1994) found that *C. maenas* is the dominant prey species of herring gulls in Germany. Dumas and Witman (1993) also found that herring gulls in USA consume *C. maenas*. Crothers (1966b) provides a list of known predators of *C. maenas* at its various life-history stages; this includes invertebrates (most plankton feeders, crabs, octopus and cuttlefish), numerous fish and bird species, and mammals (seals, otters, sperm whales and humans).

Sacculina carcini, a rhizocephalan parasite sometimes infests populations of *C. maenas* (Crothers 1966b). Male and female crabs that are infested by *S. carcini* are effectively castrated and behave like ovigerous females (Rasmussen 1959). Crothers (1966b) reported that *C. maenas* can be parasitised by other species: *Carcinonemertes*

carcinophila (Nemertini), *Fecampia erythrocephala* and *Microphallus similis* (Platyhelminthes), *Portunio maenadis* (Isopoda) and *Thelothania maenadis* (Protozoa). No *C. maenas* in Victorian waters (Australia) has been infested with *S. carcini* (M. Sinclair, pers. obs.).

Environmental factors may also limit the distribution of *C. maenas*. First, exposed coastlines are relatively unlikely to harbour populations of *C. maenas* (see Crothers 1966b). Second, in waters colder than those in Maine, Berrill (1982) suggested that populations of *C. maenas* may be unable to establish themselves – mass mortalities have been reported coinciding with severe winters (Welch 1968).

Possible ecological impacts in Victoria

Naylor (1965b) referred to *C. maenas* as a cosmopolitan species. Joska and Branch (1986) considered that *C. maenas* constitutes a threat to the local fauna of South Africa because of its non-selective predatory habits. Griffiths *et al.* (1992) proposed that *C. maenas* may have an impact on sheltered shores, but would be unlikely to impact exposed shores. *C. maenas* has been implicated in the decline of the commercially harvested soft-shell clam, *Mya arenaria*, in northern America – subsequent action was taken by harvesters against *C. maenas* (Joska and Branch 1986). Cohen *et al.* (1995) and Grosholz and Ruiz (1995) predicted that *C. maenas* could alter community structure and ecological interactions along the east coast of North America.

Based on its broad diet, aggressive nature and ability to survive in a wide range of conditions, *C. maenas* may have an impact wherever it is introduced, including Victoria. However, Joska and Branch (1986) pointed out that the establishment of *C. maenas* in Victorian waters did not appear to have any dramatic effects on local mollusc populations. In Victoria, the effects of *C. maenas* on local fauna may be restricted to shallow waters; however, these effects are difficult to estimate, as the abundances of *C. maenus* are temporally variable (M. Sinclair, unpublished data).

The Centre for Research into Marine Pests, in Tasmania, is investigating controlling populations of *C. maenas*, which have established there in high numbers, using infertile *S. carcini* (R. Thresher, pers. comm. 1995). *C. maenas* appears more abundant in Tasmania than in Victoria, hence its impact in Victoria is probably less than in Tasmania.

Styela clava Herdman 1881.

Description and geographical range

Styela clava is a solitary ascidian. Individuals may be stalked or sessile with a total length up to 16 cm (Holmes 1976; Kott 1976). *S. clava* is indigenous to the north-

western Pacific, its natural range being Japan, the Sea of Okhotsk, the coasts of Korea and southern Siberia and the coast of China to at least as far south as Shanghai (Millar 1960; Abbot and Johnson 1972).

Areas and means of introduction

Styela clava has been introduced into the UK and Europe. It was first collected in the UK in 1953 at which time it was described as a new species, *S. mammiculata* (Millar 1960; Wallace 1961). By the early 1970's it had increased its range in the UK and was known from Ireland, the channel coast of France and the Netherlands (Abbot and Johnson 1972; Guiry and Guiry 1973; Buizer 1980). It is present in California, to which it was probably introduced in the late 1920's, and was found on the Atlantic coast of the USA in 1970 (Abbot and Johnson 1972; Berman *et al.* 1992)

The first Australian record of *Styela clava* was for specimens collected in Hobsons Bay in the north of Port Phillip Bay (Holmes 1976). This was also the first record of the species from the southern hemisphere. Subsequently the species has been collected from Station Pier, northern Port Phillip Bay (Kott 1985). The records from Hobsons Bay and Station Pier remain the only records from Australia (Kott 1985).

Because the larval life is short and the adults are epifaunal, the introduction of *Styela clava* to new areas is most probably due to the transport of adults as fouling organisms on ships' hulls. Accidental introduction with the introduction of oysters has also been suggested (Holmes 1976; Carlton 1985; Hutchings *et al.* 1987)

Habitat and biology

Styela clava occurs subtidally, to depths of at least 25 metres, and may be found intertidally up to mid-shore level in sheltered areas or under stones (Holmes 1976; Buizer, 1980; Sims 1984). *S. clava* occurs in areas of fully marine salinity but has a limited capacity to regulate body volume when exposed to low salinity (Sims 1984). The species prefers sheltered areas with low wave energy (Abbot and Johnson 1972; Holmes 1976). Temperature ranges tolerated by *Styela clava* are 2 to 23°C in the UK, -2 to 22°C in the Netherlands and 10 to 23°C in Victoria, Australia (Holmes 1976; Buizer, 1980).

In the UK reproduction in *Styela clava* occurs in all but the coldest two or three months of the year, but is most marked in the summer and the peak period for juvenile settlement is mid to late summer (Wallace 1961; Holmes 1976). In Hobsons Bay, Victoria, *S. clava* spawns during the summer and the success of reproduction and the survival of adults may be adversely affected by lowered salinity due to freshwater from the Yarra River (Holmes 1982). The maximum free-floating life of eggs and larvae is 24 hours (Holmes 1976). *S. clava* attaches to hard substrata, such as stones, rocks and pier piles, but has been recorded from softer substrata, such as peat (Buizer, 1980). *S. clava* may itself provide a substratum for settlement of juveniles of its own species, and also for settlement of other species of ascidians, sponges, hydroids, bryozoans and seaweeds (Buizer, 1980). Despite its short free-floating life, *S. clava* appears to be capable of spreading rapidly in areas where it has been introduced (Millar 1960; Guiry and Guiry 1973; Buizer 1980).

Styela clava is said to be a secondary settler, colonising surfaces that already carry a well developed epibiota. Densities of up to 500 adults m⁻² have been recorded in the UK (Holmes 1976). In the U.S.A. *S. clava* is a competitive dominant, at least in the more southerly areas it has colonised, and occurs densely in areas formerly dominated by the mussel *Mytilus edulis*. It has also been suggested that *S. clava* could competitively exclude the anemone *Meretridium senile* if it increases in abundance in more northerly areas (Berman et al. 1992).

Styela clava is a filter feeder. Water transport rates in laboratory experiments at 10°C ranged from 0.23 to 0.64 litres/hr/g wet tissues weight; transport rates increased with size and temperature and decreased in static water (Holmes 1973). Laboratory experiments have shown that *S. clava* is a predator of oyster larvae, and through competition for food may influence growth and survival of newly settled oyster larvae (Osman et al. 1989; Zajac et al. 1989). Field experiments have failed to demonstrate a reduction in larval settlement due to ascidians, probably because any effects the ascidians may have are obscured by other factors which influence larval settlement (Young 1989).

Possible ecological impacts in Port Phillip Bay

The impact of *S. clava* on native species is not known. The limited distribution of *S. clava* shows that any effects which may occur in Port Phillip Bay will be restricted to a small area of the bay. At high population densities *S. clava* could adversely effect the survival and growth of co-occurring species, or could competitively displace native species, as seen in the displacement of *Mytilus* in communities in North America. *S. clava* may provide a substratum for the attachment of native species

Molgula manhattensis (De Kay, 1843)

Description and geographical range

Molgula manhattensis is a small, solitary ascidian. The body is circular to oval in shape and up to about 2.5 cm high. The natural range of the species is along the Atlantic coast of the USA from Maine to Louisiana (Kott 1985).

Areas and means of introduction

Molgula manhattensis has been recorded from the U.K. (Marine Biological Association 1957; Stubbings and Houghton 1964), Norway (Dybern 1969; Millar 1971) and Japan (Tokiooka and Houghton 1972; Kott 1985).

Molgula manhattensis has been recorded from the Brisbane River, Queensland, and questionably from New South Wales (Kott 1985). Introduction into Queensland was assumed to be as a fouling organism on ship's hulls, and may have occurred on several occasions with resident populations being wiped out (by low salinity due to summer rains) between introductions (Kott 1976).

Kott (1976) recorded *Molgula manhattensis* from the Newport Power station, Yarra River in the north of Port Phillip Bay. There have been no subsequent records (Kott 1985). It is assumed that the species was introduced as a fouling organism on ships.

Habitat and biology

Molgula manhattensis is found from the low intertidal zone to a depth of about 100 m (Marine Biological Association 1957; Kott 1985).

Little is known of the biology of *Molgula manhattensis* (Kott 1976). The species tolerates reduced salinities (to <10‰), water temperatures in the range 1 - 19°C and becomes sexually mature at a diameter of 1.2 cm (Dybern 1969; Kott 1976). In the USA, *M. manhattensis* is an early and dominant member of marine fouling communities and its abundance may impede the collection and growth of bivalve spat during aquaculture operations (Otsuka and Dauer 1982; Morales-Alamo and Mann 1990; Flimlin 1992). Kott (1976) assumed the reproductive period of specimens introduced into Queensland to be prolonged since the related species *Molgula tubifera* in the U.K. breeds during all seasons except winter. In fact, *Molgula tubifera* is a synonym for *Molgula manhattensis* (Dybern 1969) and at Plymouth in the U.K. *M. manhattensis* is said to breed throughout the year (Marine Biological Association 1957). In Japan *M. manhattensis* spawns during the winter when the average air temperature is about 5°C (Tokioaka and Kado 1972).

In its natural range, the settlement of *M. manhattensis* on oyster cultch and on submerged test panels may occur over much of the year. Some studies have found settlement occurs abundantly from spring until early winter while others have found few larvae to be present in late summer and early autumn (Cory and Nauman 1970; Otsuka and Dauer 1982; Morales-Alamo and Mann 1990). Growth rate is rapid, and individuals can attain maximum size in less than 2 weeks (Otsuka and Dauer 1982). The early achievement of sexual maturity and various structural characteristics shown by *M. manhattensis* (and by members of the family Molgulidae in general) are thought to be advantageous for species living in sheltered bays where seasonal mortality due to periodic flooding, silt deposition and temperature fluctuations is likely (Kott 1976). The species is an efficient filter feeder. Individuals may filter up to a litre of seawater an hour (Kott 1976).

Possible ecological impacts in Port Phillip Bay

Given that *Molgula manhattensis* in Port Phillip Bay has been recorded only in an area influenced by heated effluent from a power station, it is unlikely that the present population (if still present in the bay) is having any obvious ecological impact. If the species were to occur in great abundance as a fouling organism, then competition with native species for food and space could occur and there is the potential for interference with the collection of shellfish spat during aquaculture operations.

Brief notes on other exotic species said to occur in Port Phillip Bay

Hydroides norvegica Gunnerus, 1768

The serpulid worm *Hydroides norvegica* is a fouling organism, common on shipping, of world wide distribution (Skerman 1960a) and found generally throughout Australia. Hutchings *et al.* (1987) suggest that *H. norvegica* was introduced to Australia from Europe while Pollard and Hutchings (1990) suggest that records of *H. norvegica* may be due to a misidentification. Some data on reproduction and factors influencing settlement are given in Wisely (1958, 1959) and Reish (1961).

Neanthes succinea (Leuckart, 1847)

The nereid polychaete *Neanthes succinea*, a northern hemisphere species, was described from Hobsons Bay by Wilson (1984) but the possible means of introduction was not discussed. The species has been present in Australia since the 1930's and has been recorded from the Swan River, Western Australia, under the name *Nereis oxypoda*. It is also known from New South Wales, China and North America (Wilson 1984).

Janolus hyalinus (Alder and Hancock, 1854)

The opisthobranch mollusc *Janolus hyalinus*, a European species (type locality Cheshire, England), has been described from Torquay, west of Port Phillip Bay, in which locality it is said to be rare under rocks in pools at mid tide level (Burn 1958). *J. hyalinus* has also been found on both the eastern and western shores of Port Phillip Bay and in New Zealand (Miller and Willan 1986). The means of introduction is thought to be as a fouling organism on ships' hulls (Hutchings *et al.* 1987; Pollard and Hutchings 1990).

Crassostrea gigas (Thunberg, 1793)

Major attempts to introduce Pacific oysters, *Crassostrea gigas*, into southern Australia were made from 1948 to 1952. During this period oysters were introduced into Mallacoota, eastern Victoria, but did not become established (Thomson 1959). There have been no subsequent attempts to introduce Pacific oysters into the natural environment of Victoria. Oysters are grown in isolated salt ponds near Avalon on the shores of Port Phillip Bay. Not only are these ponds separate from the bay but, because of the high salinity, the oysters grown there do not reproduce and settle successfully and there is no evidence that oysters have escaped from the ponds into the bay. Although there are occasional reports of *Crassostrea gigas* wild in Port Phillip Bay these reports remain unconfirmed. Pacific oysters have been found wild in Anderson Inlet, to the east of Port Phillip Bay, but the origin of these oysters is not known (Coleman and Hickman 1985).

Raeta pulchella (Adams and Reeve, 1850)

During recent benthic studies carried out by the Victorian Fisheries Research Institute in Port Phillip Bay, specimens of a bivalve provisionally identified (through the

Museum of Victoria) as *Raeta pulchella* were collected. This species is very common in muddy sediments in sheltered waters throughout Japan, Korea and Siberia (Kira 1965).

Cancer novae-zelandiae (Jacquinot and Lucas, 1853)

The crab *Cancer novae-zelandiae*, native to New Zealand, was described from Tasmania and Port Phillip Bay in 1930 (McNeill and Ward 1930). It has not been recorded from Port Phillip Bay since then (Pollard and Hutchings 1990). Introduction to Tasmania may have been with introductions of oysters from New Zealand, but the how it was introduced to Port Phillip Bay is not known.

BRIEF NOTES ON OTHER EXOTIC SPECIES RECORDED FROM VICTORIAN
WATERS BUT NOT FROM PORT PHILLIP BAY

Four species (Table 2) have been recorded from the Victorian coast but not from Port Phillip Bay. In addition, the Pacific oyster, *Crassostrea gigas*, is also known only from outside of Port Phillip, even though there are occasional, anecdotal, reports of its presence in the bay.

Polycera hedgpethi Marcus, 1964

The opisthobranch mollusc *Polycera hedgpethi* was originally described from California where it feeds on the bryozoan *Bugula* (Marcus 1964; Lance 1966; McDonald and Nybakken, 1978). In Australia *P. hedgpethi* is found in Western Australia, New South Wales and the extreme east of Victoria, where its occurrence may be due to transport by water currents from New South Wales (R. Burn, Honorary Associate, Museum of Victoria). *Bugula* species, on which *P. hedgpethi* feed, are cosmopolitan in fouling communities and *P. hedgpethi* is thought to have been introduced into Australia as a fouling organism (Hutchings *et al.* 1987; Pollard and Hutchings 1990). *P. hedgpethi* has also been recorded from South Africa (Gosliner 1982).

Okenia plana Baba, 1960

The opisthobranch mollusc *Okenia plana* Baba was originally described from Japan. It has been introduced into Australia, possibly as a fouling organism (Hutchings *et al.* 1987; Pollard and Hutchings 1990) and is found in Queensland, New South Wales and the extreme east of Victoria (R. Burn, Honorary Associate, Museum of Victoria).

Tanais dulongi (Audouin, 1826)

The crustacean *Tanais dulongi*, reported as an exotic species (information provided by Dr Sebastian Rainer, CSIRO Division of Fisheries, Hobart) is common along the open

coast of Victoria and may be endemic (Dr. G.C.B. Poore, Curator of Crustacea, Museum of Victoria, personal communication).

Cirolana harfordi (Lockington, 1877)

The isopod *Cirolana harfordi* has been described from Lorne on the west coast of Victoria (Bruce 1986). In California (the type locality) *C. harfordi* is found throughout the intertidal zone and occurs under rocks on sandy beaches, amongst mussel beds and amongst or under other epifaunal species such as tunicates and sponges, grows to about 20 mm in length, is most active at night and is able to tolerate salinities reduced to 50% that of seawater for more than 2 days (Hewatt 1937; Brusca 1966; Kirby and Harbaugh 1974; Johnson 1976a,b). Bruce (1986) examined only a single individual from Lorne, but in its native range the species may occur in great abundance and population densities in excess of 14,000m⁻² have been recorded (Johnson 1976a) .

Cirolana harfordi is a scavenger, but is also a voracious predator feeding on small polychaetes and amphipods and may only need to feed once in 3 to 5 weeks (Johnson 1976a; Ricketts et al. 1988). As a scavenger, a predator of small invertebrates and a species capable of reaching very high population densities, *C. harfordi* could potentially impact on local intertidal species

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Table 3. Summary of biological data for exotic species introduced into Port Phillip Bay.

Temperature/salinity tolerances are based on data appearing in the literature and do not necessarily represent extreme limits of tolerance.
A, ascidian; B, bivalve; C, crustacean; P, polychaete

Species/Natural range	Habitat	Temperature/salinity tolerance	Reproduction	Presence in Port Phillip Bay	Comments
<i>Sabella spallanzanii</i> (P) Mediterranean and Atlantic coast of Europe	Epifaunal, tube dwelling, subtidal to 30 m depth. May inhabit soft substrata where there are stones, shell fragments etc to provide a site for attachment	11 to 29°C. 38‰	Spawns in Winter in natural range. Possible summer spawner in Port Phillip Bay.	Abundant in the Geelong Arm. Range appears to be spreading northwards along the western shore of the bay. No known predators in the bay.	Can interfere with scallop harvesting. May affect nutrient cycling and fish communities.
<i>Boccardia proboscidea</i> (P). Pacific coast of N. America, Japan	Intertidal to 100m depth Burrows/inhabits tubes in a wide range of habitats including soft rocks, crevices, seagrass beds	8.5 to 21°C. Brackish to fully marine (21.5-34.8‰)	Spring to late summer and early autumn. Pelagic and non-pelagic larvae produced.	Abundant high in the intertidal zone adjacent to effluent drains at the Werribee sewage treatment farm.	Opportunistic species reported from organically enriched areas in other parts of the world.
<i>Pseudopolydora paucibranchiata</i> (P) Japan, Russian coasts of the sea of Japan.	Sandy-mud sediments, intertidal and subtidal, in bays and estuaries. Constructs tube of fine sand and silt	8.5 to 21°C. Brackish to fully marine (21.5-34.8‰)	Breeds during much of the year (in California). Larvae pelagic. Sexually mature about a month after hatching.	Intertidally and subtidally off the Werribee sewage treatment farm. Most abundant subtidally	In pollution studies has been found to characterise semi-healthy areas

Table 3 (continued)

Species/Natural range	Habitat	Temperature/salinity tolerance	Reproduction	Presence in Port Phillip Bay	Comments
<i>Musculista senhousia</i> (B). Western Pacific - China, Siberia, Japan, Kurile Is.	Intertidal to 20 m depth. Infaunal in sand or mud substrata or epifaunal on hard substrata. Secretes byssus	0.8 to 22°C. Brackish to marine (from 18‰ up)	Spawning period variable, mainly during summer and autumn. Pelagic larvae	Common in Corio Bay. Point Wilson Port Melbourne	Opportunistic species. On soft substrata dense mats of mussels may exclude underlying fauna.
<i>Theora lubrica</i> (B). Pacific coast of Asia - Indonesia, Philippines, Thailand, China, Japan	Inhabits muddy sediments subtidally in bays.	9 to 26°C. Brackish to marine (from 18‰ up)	Extended period of spawning. Recruitment occurs throughout the year. Pelagic larvae	Very abundant throughout Port Phillip Bay	Very fast growth rate particularly at intermediate (c 20°C) temperatures. May show large fluctuations in population density. Sensitive to anoxia but populations may recover quickly when conditions improve
<i>Corbula gibba</i> (B). Europe - Norway to the Mediterranean	From shallow sublittoral zone to 150 m. Infaunal in mud containing gravel.	-1 to 16°C. 27 to 33‰	Spawning occurs in late summer and autumn. Spat settlement reported for all seasons of the year.	Abundant throughout Port Phillip Bay. A major item in the diet of globefish and also found in the diets of 8 other fish species studied.	Tolerates very low oxygen levels. Is often characteristic of polluted areas, is found at edge of anoxic and azoic zones and is a pioneer species in areas recovering from pollution

Table 3 (continued)

Species/Natural range	Habitat	Temperature/ salinity tolerance	Reproduction	Presence in Port Phillip Bay	Comments
<i>Pyromaia tuberculata</i> (C). Eastern Pacific from California south to Colombia	From low in the intertidal zone to 415 m depth. On soft substrata, also amongst rocks and amongst algae and tunicates on wharf pilings.		Ovigerous females found throughout the year (in eastern Pacific) but frequency highest in spring and summer. Possibly breeds autumn/winter in southern hemisphere.	Appears to be well established in Port Phillip Bay. Found in the diets of 8 species of fish studied.	
<i>Carcinus maenas</i> (C) Widespread in European waters	Intertidally from mid to low shore. Found on sheltered shores (e.g. mud/sand shores, rocky habitats) not exposed coasts.	Approximately 4-18°C in European waters; may vary in more southern and northern countries. Salinity tolerance 4-33‰. Prefers salinities around 27‰	Copulates during summer; females ovigerous during winter. Larval life is temperature dependent: 75 days at 10°C, 13 days at 25°C. High water temperatures or severe winters prevent breeding.	Widespread mainly on mudflats, among seagrass or in holes; also in weedy habitats on rock platforms.	Introduced into all continents except Antarctica. Omnivorous. May alter community structure and reduce density of native fauna.

Table 3 (continued)

Species/Natural range	Habitat	Temperature/salinity tolerance	Reproduction	Presence in Port Phillip Bay	Comments
<i>Styela clava</i> (A) N-W Pacific - Japan, Korea, Siberia, China	From midshore level to at least 25 m depth. In sheltered areas of low wave energy. Attached epifaunally to hard substrata.	-2 to 23°C. Marine. Very limited capacity to regulate body volume in low salinity.	Breeds in summer. Free-living life about 24 hours. Reduced salinity impairs reproduction.	Found epifaunally in Hobsons Bay	Introduced into USA and in some areas occurs as a competitive dominant in areas formerly dominated by <i>Mytilus</i>
<i>Molgula manhattensis</i> (A) Atlantic coast of USA from Maine to Louisiana	From low spring tide level to depths of about 30 m	1 to 19°C. Tolerates salinities down to <10‰	Breeds during all seasons in UK. Settles mainly during spring and early summer in native range	Recorded from the Yarra River in 1976. No subsequent records.	Early and dominant member of fouling communities in its native habitat. Rapidly reaches sexual maturity.

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