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A REVIEW OF RAPID RESPONSE OPTIONS FOR THE CONTROL OF ABWMAC LISTED INTRODUCED MARINE PEST SPECIES AND RELATED TAXA IN AUSTRALIAN WATERS

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SUMMARY

Rapid response to the *Mytilopsis* sp. invasion in Darwin in 1999 was facilitated by ready access to information on control of a close relative, the zebra mussel *Dreissena polymorpha*. It was recognised that similar information would be necessary in order to respond rapidly to other marine pest species likely to establish in Australia. The Centre for Research on Introduced Marine Pests (CRIMP), supported by the National Heritage Trust Coast and Clean Seas initiative, undertook to develop a 'Rapid Response Toolbox' that would provide a summary of available response strategies. This literature review forms the basis of the Rapid Response Toolbox.

Rapid response is the preferred approach when barrier controls have failed. Successful rapid response requires: early detection, a supportive legal framework, a capacity to act, an ability to quarantine the infested area, the capacity to reduce the risk of future infestations, and the tools to eradicate the quarantined population. Available technologies are limited to eradications of pests with restricted distributions or restricted life history stages.

A constraint of eradication is the availability of specific control techniques for target pest species with minimal collateral damage to other species or their environment. Only a few taxa-specific aquatic pesticides have been developed (eg. TFM (3-trifluoromethyl-4-nitrophenol) for freshwater lampreys) and none are available for the marine environment. Successful eradication of introduced marine populations has only occurred where incursions have been restricted to small areas. These have involved the use of chemicals (*Mytilopsis* sp. in Darwin), physical removal and burial (*Perna canaliculus* in Gulf St Vincent), physical removal of potential hosts (parasitic sabellid shell borer in California), and repeated physical removal (*Caulerpa taxifolia* in Cala D'Or, Spain).

We recommend the use of a risk assessment approach to weigh the relative costs, benefits and risks of eradication versus the option of taking no action. To assist in this process, a rapid response decision tree is proposed in which the branches are: establishment of magnitude of problem, setting and clarification of objectives, consideration of full range of alternatives, determination of risks, reduction of risk, assessment of benefits/risks of full-scale implementation, and monitoring. A decision index is suggested to assess the trade-offs between environmental and economic factors.

This review of possible response options concentrates on those species identified as posing the greatest risk to Australia by the Australian Ballast Water Management Advisory Council (ABWMAC). Since many of the response options are not species specific we have broadened the review to include taxa similar to those listed by ABWMAC and additional groups for which literature was available.

There are several promising approaches to control **toxic phytoplankton** in the water column, however no method for removing spores and cysts from the sediments has been identified. Until this can be achieved the eradication of toxic phytoplankton from an area is not feasible. A fundamental lack of understanding of the factors that initiate and control blooms of toxic phytoplankton species limits the potential for developing preventative measures.

Caulerpa taxifolia and *Undaria pinnatifida* are two **macroalgal** species that have been successfully removed by handpicking combined with ongoing monitoring and further removals. The use of this method is critically dependent on early detection of incursions but is labour intensive and therefore expensive. Chemical methods have not been effective – improved application methods are required. Biological control using generalist algal predators holds little promise as an eradication tool. Similarly, pathogens, parasites, viruses and endophytes may reduce the viability of a population but are unlikely to cause its demise and are also in most cases not species-specific.

Eradication or control of the ctenophore ***Mnemiopsis leidyi*** provides a major challenge. Physical or chemical methods are unlikely to be effective in controlling this species. Proposed candidates for use as biological control agents are several fish species, however these represent high risks to the already

invaded ecosystem as they are generalist feeders. Enhancement of local fish populations provides one possible avenue for control but the capacity of these slowly growing ‘stable’ populations to respond to a rapidly growing and variable ctenophore population requires further examination.

Asterias amurensis and other echinoderms can be physically removed from relatively small areas and there is considerable expertise in this form of control around marine farms in shallow waters. Biologically vectored agents will be required to control or eradicate dispersed populations. Suitable parasites or predators have yet to be identified; genetic manipulation may provide a more species specific approach. Habitat management may assist in controlling pest population if subsequent recruitment can also be reduced.

Control of **bivalve molluscs** has received considerable attention. Chemical control methods have predominated as physical removal, unless used early in an invasion, is generally regarded as too environmentally damaging. The ability of bivalve molluscs to close their shells in the presence of noxious chemicals increases the time over which chemical treatment must occur – polyquaternary compounds may circumvent this problem. Currently available chemicals are not highly specific and application methods that limit their dispersal need to be developed. A variety of physical techniques have proven successful against the zebra mussel in industrial plant situations.

A commercial fishery could reduce numbers of ***Carcinus maenas*** if markets can be developed for the catch. Physical removal using traps does not seem to be particularly effective. Chemical control using poisoned baits is a viable method for removing adults in local areas; repeated applications are required to maintain control. More specific arthropod moult regulators may have promise as a more specific biocide but these have not been extensively tested. Parasites, parasitic castrators, native predator enhancement and genetic or molecular techniques may provide potential options for long-term control.

Physical removal of ***Sabella spallanzanii*** is complicated by the capacity of the worm to regenerate from body fragments. Hot water treatment may be useful to eradication localised infestations. Copper may also be an effective chemical agent. Ultrasonic techniques could have potential outside aquaculture operations. The shell-boring sabellid *Terebrasabella heterouncinata* appears to have been eradicated from outside a California abalone facility by preventing further release of worms from the facility, reducing the adult populations of the pest and reducing the abundance of the most susceptible native host in the area.

Vibrio cholera is present in waterways worldwide and current ballast water treatment methods will have little effect on its transport by shipping. The most effective control is by ensuring safe water supplies and adequate sanitation.

Fish have been controlled and/or eradicated from relatively small isolated freshwater bodies using chemicals or dewatering. Physical removal has not proven a successful eradication method to date. Control of fish in open environments has yet to be achieved – new developments in molecular biology may provide opportunities to do this.

Physical removal of ***Spartina*** **sp.** is complicated by its extensive root structure. Smothering may take 6 months. Mechanical methods have had variable success. Herbicides currently provide the only cost-effective approach.

Attempts to control **boring isopods** and **molluscs** have included use of durable and/or treated timbers. However, sphaeromatid isopods are quite resistant and new chemical options are being investigated.

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CONTENTS

APPENDICES

1 INTRODUCTION

The extent of the introduced marine species problem in Australia became apparent with the outbreaks of highly visible introduced species (eg. *Asterias amurensis* and *Mytilopsis* sp.) capable of adversely impacting on industry, aquaculture and biodiversity. Until recently, there was little research on the problem's extent in Australia (though see Pollard and Hutchings 1990a, 1990b; Hewitt *et al*. 1999). However since 1995, CSIRO's Centre for Research on Introduced Marine Pests (CRIMP) and State agencies have started baseline surveys of ports and marinas, locations which are likely to be the first port of call for many overseas vessels and their attendant alien flora and fauna. This is the first stage in assessing the existing risk of introduced marine species to Australia.

Port surveys, literature searches and museum collections have indicated that there are more than 200 introduced and cryptogenic species in Australia (C. Hewitt, CRIMP, pers. comm.). This number is likely to be an underestimate as only 21 of the 72 trading ports in Australia have been surveyed to date and 165 introduced and cryptogenic species were identified from Port Phillip Bay alone (Hewitt *et al*. 1999). Of the >200 introduced species, 12 are classified as pest species and are included in the 1995 ABWMAC target pests species list (*Alexandrium catenella, Alexandrium minutum, Alexandrium tamarense, Gymnodinium catenatum, Asterias amurensis, Carcinus maenas, Corbula gibba, Crassostrea gigas, Musculista senhousia, Sabella spallanzanii, Undaria pinnatifida* and *Vibrio cholerae*). A further two species (*Mnemiopsis leidyi* and *Potamocorbula amurensis*) are listed as ABWMAC target species but have not yet been detected in Australian waters. Four species (*Mytilopsis* sp., *Caulerpa taxifolia* (aquarium strain), *Codium fragile* spp. *tomentosoides* and *Sargassum muticum*) that are likely to have major impacts in Australia if introduced are included on the 1999 Interim Pest List produced by the Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions. The incursion of *Mytilopsis* sp. in Darwin Harbour in 1999 indicates that this species is likely to be reintroduced (Bax 1999; Ferguson 2000; Willan et al 2000; Campbell and Hewitt in prep). All these 18 species are included in this review.

The economic cost of the negative impacts caused by aquatic exotic species is significant. Pimental *et al*. (2000) estimated conservative economic costs attributable to exotic fishes in the United States at US$1 billion annually. In 1993 in the USA the damage caused by and cost of control of the zebra mussel (*Dreissena polymorpha*), Asiatic clam (*Corbicula fluminea*) and the European green crab (*Carcinus maenas*) was estimated to be US$4.4 billion annually. Aquatic weed control cost US$110 million annually, with purple loosestrife costing US$45 million annually (Hall and Mills 2000).

It is universally recognised that prevention is the cheapest and most effective response to the marine pest problem. This requires a comprehensive risk-based strategy addressing all major vectors likely to bring alien species to Australian shores. The processes of determining vectors and preventing incursions in the marine environment are important issues (eg. Campbell and Hewitt 1999; Carlton 1999a; Lewis 1999; Thresher *et al*. 1999), but beyond the scope of this review. However even the best risk-based strategy would not be expected to reduce the risk of new invasions to zero, neither should it be expected that none of the >200 introduced or cryptogenic marine species in Australia will become pests as environmental conditions change or they spread domestically. There are well-documented cases of marine species becoming pests under new environmental conditions decades after being first detected. Examples include: the Asian mitten crab, *Eriocheir sinensis*, that became a pest 75 years after first detection and the wood-boring gribble (isopod) *Limnoria tripunctata*, that became a pest in the Long Beach - Los Angeles Harbour area after 65 years (Crooks and Soulé 1999). Future pest outbreaks are to be expected in Australia.

In 1999, *Mytilopsis* sp. was eradicated from three Darwin marinas. The scale, success and the cost of this operation prompted national authorities to consider what Australia required to protect itself against future incursions of alien marine pests that manage to pass through quarantine barriers. The Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions was formed in August 1999 to provide national direction on this issue and reported by the end of the same year (SCC/SCFA 1999).

A rapid response capacity for future incursions requires:

- early detection (including positive genetic identification of species with invasive strains);
- a supportive legal framework;
- a capacity to act (requiring suitable funding and local/national support);
- an ability to quarantine the infested area if necessary; and
- the tools to eradicate the isolated population (Bax 2000).

Rapid response to *Mytilopsis* sp. in Darwin was facilitated by ready access to available information on the control of a close relative, the zebra mussel *Dreissena polymorpha* (Bax 1999). It was recognised that similar information would be necessary to respond to any of the species on the target pest list found in Australian waters. Towards this end, CRIMP was tasked with developing a ‘Rapid Response Toolbox’ providing specific strategies to respond to the ABWMAC listed species if (once) detected in Australia. Because many of the response techniques have low specificity they will also apply to related taxa.

The first step in this process is a review of terrestrial, freshwater and marine control and mitigation literature, examining why some methods are successful and why others fail, leading to the development of a rapid response decision-tree. Secondly, potential strategies for control of the ABWMAC species and related taxa are reviewed. This review will form the basis for a toolbox of control measures that could be used once a pest species is detected or establishes in Australia. The Australian regulations for use and availability of chemicals for chemical control in the marine and estuarine environment are summarised in Appendix A. A glossary of terms and acronyms is provided in Appendix B.

2 PEST CONTROL AND ERADICATION

The history of terrestrial pest control varies from country to country and dates back thousands of years for pests affecting food crops (Debach 1974; Crosby 1986). Control methods have developed rapidly in the 20th century and Integrated Pest Management has seen the integration of physical, chemical and biological control. By comparison, marine pest control is in its infancy. While there is a long history of physically or chemically protecting man-made structures (especially ships) and/or cleaning sessile organisms from these, there is little history in the control of mobile or dispersed organisms.

Three management technologies are generally applied to control pest species: mechanical/physical (eg. fire and physical removal), chemical (eg. inorganic and organic pesticides) and biological (habitat, pathogens, parasites, predators and genetic manipulation) control. The development of highly effective synthetic organic pesticides such as DDT (dichloro-diphenyl-trichloroethane) in the 1940s, led to extensive campaigns to chemically eradicate insect pests for agricultural and health reasons. The generally disappointing results led to the modern practice of Integrated Pest Management (IPM) that uses a mixture of chemical, mechanical and biological techniques depending on the circumstances. Eradication is explicitly not a goal of IPM except in extremely limited circumstances where the target pest is confined to a very limited range. For most pests the goal of IPM is not eradication but only to maintain the pest population below an economic threshold (Dahlsten *et al*. 1989).

Available technologies generally limit eradication to restricted populations or populations with restricted life history stages. It is in essence a rapid response to what is seen as a temporary stage in the colonisation of a new area. It is implemented in a policy arena composed of laws and regulations, private and public organisations, government agencies, industry, interest groups, and private individuals (Dahlsten *et al*. 1989). While existing technologies provide the upper and lower bounds of what can be achieved with an eradication program, the expectations and resources of the many interdependent and often conflicting interest groups operating in the policy arena both create the market for developing eradication technologies and promote or limit their application. There are rarely sufficient data to accurately estimate the costs and benefits of a particular eradication attempt and competing interest groups can attempt to influence the decision, based on individual values and perceptions of the associated economics, politics, technology and environmental values.

Risk assessment can provide a formal framework to weigh the relative costs, benefits and risks of a continued pest incursion against those of attempted eradication or control (Bax *et al*. 2001). However, given the time available to decide on a rapid response, the final decision will be more subjective than usual. However, it is important that control measures should not be delayed as, second to prevention, a rapid response to incursions is the most economic approach to dealing with incursion of undesirable introduced species. Given the difficulty of predicting which alien species will become invasive, Crooks and Soulé (1999) recommend that eradication should be early and vigorous.

3 SUCCESS AND FAILURE

3.1 Marine case studies

Optimally a control method should be highly selective, have no long-term effects on the environment, human or other life, and be cost-effective and easy to use. This will rarely be the case and managers considering eradication will often be faced with some difficult choices. One of the main constraints for eradication (once the pest has exceeded the level where it can be individually removed or smothered) is the lack of highly specific control techniques that can be used over a wide area. Biological control has yet to be proven as an approach to controlling marine pests and, in any case, is more likely to reduce the numbers of the pest species than eradicate it. There is the potential to develop biocides of high specificity to kill distributed pest populations, (eg. the chemical TFM was developed to control two freshwater fish species: lamprey and ruffe (Busiahn 1996)), but we are aware of no similar research for marine species. Development of highly specific control techniques will usually require good knowledge on the particular physiology, habitats and/or ecology of the target pest. Such knowledge is rarely available, even for the most likely future marine invaders.

The decision to eradicate a potential marine pest species will require a balancing of the benefits and hazards of the eradication effort against the benefits and hazards of leaving the potential pest to spread unrestricted (Bax *et al.* 2001). It is to be expected that the failure rate will be high, although a generally high failure rate should not be used as an excuse not to proceed with a specific eradication attempt. This decision needs to be balanced by the potential damage that the pest could cause locally, nationally and regionally if left unchecked. A pre-existing strategic plan for controlling a likely pest species is one way to reduce the risk of unwarranted eradication attempts and one way to guard against lack of action when eradication could be achieved. This was one of the key findings of the *Mytilopsis* sp. eradication in Darwin, and is one of the major difficulties with the current *Caulerpa taxifolia* eradication in San Diego, where there are no clear lines of authority, no clear funding and a lack of appropriate permits (B. Hoffman, National Marine Fisheries Service, San Diego, pers. comm.).

Mytilopsis sp. was successfully eradicated from three locked marinas in Darwin harbour using chlorine and copper sulphate. Fouled vessels were treated *in situ* where possible. Vessels exposed to the mussels but outside the marinas were surveyed and hauled out of the water onto hard stands for at least a week if found to be carrying the mussel. Many factors contributed to the successful eradication: whole of government support, community support, early detection, rapid response, legal capacity to enter, seize or destroy private property, small water bodies separated from the local marine environment by double lock gates, ability to track exposed vessels and pre-existing information on chemical treatments for related taxa (Bax 1999, Ferguson 2000). While the non-specific damage was high (everything in the water was killed), it was restricted to three locked marinas representing environments that were already substantially modified and polluted. Potential damages to marine infrastructure, fisheries and the environment were much higher if the incursion had escaped to the open ocean, where simple eradication techniques could not have been applied using existing technology.

Perna canaliculus was successfully eradicated from the shipping channel adjacent to the Outer Harbour wharf in the Gulf St Vincent in South Australia in 1996. A mature population of 12-24 mussels, all of a similar size attached to a razor fish shell was collected during a research dive. Subsequent dredging and dive surveys found one more mussel but recent surveys of areas likely to be colonised by a reproductive event based on water currents found no more mussels (V. Neveraskis, SARDI; pers. comm; PIRSA 1999).

An established population of a parasitic sabellid polychaete shell borer, *Terebrasabella heterouncinata* found outside an infected abalone aquaculture facility in California in 1996 was eradicated based on the theoretical transmission threshold (Culver and Kuris 1999), using a three-phase eradication program:

1. Aquaculture facility was screened to prevent further releases of adult worms;
2. Facility-associated debris that could harbour worms was removed and destroyed; and
3. 1.6 million mollusc hosts (or potential hosts) were removed so that the transmission threshold was not met.

This three-way approach not only targeted the pest but also the host required for continuance of the established pest population. Surveys of potential host-molluscs in 1998 found infection rates had dropped from 32% to zero. Specifically they removed 1.6 million individuals of the most highly susceptible and preferred host in the intertidal area, the gastropod, *Tegula funebralis.* A screen was also installed at the associated abalone aquaculture facility to prevent the release of additional infested material (the source of the established intertidal population) and all such material was removed from the intertidal area. This three-phase approach targeted both the pest and the host. Results strongly suggested that the source of the population was the release of thousands of adult sabellids in the shells of the escaped gastropods and shell debris from the facility, rather than the release of benthic sabellid larvae in the discharge water (Culver and Kuris 2000). Surveys in 1998 found that infestations of sentinel molluscs had been eliminated and the sabellid had been eradicated. Some of these methods may have applicability in controlling *S. spallanzanii* on aquaculture structures (eg. commercial mussel lines and oyster-spat baskets) thus reducing spread from infested sites.

Caulerpa taxifolia was temporarily eradicated in Cala D'Or, Spain in 1992 when an area of 200 m^2 (spread over 1 hectare) of the algae was found upon the sediments within an anchorage (Meinesz 1999). The anchorage was closed 2 days after discovery, and divers manually removed the plants within a month. Manual removal of any re-establishing plants was repeated in 1993, and in 1994 eradication appeared to have been successful. Unfortunately, in 1995 *Caulerpa taxifolia* was found outside Cala D'Or, however in much larger quantities and so manual removal was not feasible.

These successful eradications all occurred on restricted populations that were found soon after establishment. If the populations had spread more widely, the same techniques could not have been used, or would have had a smaller chance of success. This is a pattern also seen in terrestrial pest eradications. For example, an infestation of the Asian citrus blackfly (*Aleurocanthus woglumi*) discovered in Key West, Florida in 1934 was eradicated by a three year spray campaign using a mixture of paraffin oil, whale oil, soap and water. The campaign cost about $200,000 and the fly never spread beyond the island. When the same species was discovered in Fort Lauderdale the attempted eradication campaign was unsuccessful because the areas was too large and the pest could not be contained as it had been on Key West (Simberloff 1997).

Early and accurate recognition increase the chances of a successful rapid response. *Asterias amurensis* was incorrectly identified as the native seastar *Uniophora granifera,* and it took until 1992 to correct this mistake (K. Gowlett-Holmes, CSIRO, pers. comm.). By the time the pest was correctly identified it was in sufficient abundance that the (admittedly slim) chances of a rapid eradication had passed. In contrast, *Mytilopsis* sp. was provisionally identified as a dreissenid mussel, a relative of the pestilent zebra mussel, raising immediate concern, and the relevant authorities informed within 2 days of the initial discovery.

In Britain, control measures have only been employed on species that are a nuisance. The effectiveness of the methods used varies, although no non-native marine species has ever been eradicated from British waters using a directed approach (Eno *et al*. 1996). Examples of unsuccessful eradications include the Atlantic gastropod, *Urosalpinx cinerea*, in the 1950's and the Japanese alga, *Sargassum muticum*, in southern England in the 1970's (Hancock 1959; Critchley *et al.* 1986). Unsuccessful attempts for the large-scale removal and destruction of *U. cinerea* were conducted in

Essex Rivers, UK, using physical and chemical control methods in the 1950's. This included dredging and trapping, and chemically impregnated barriers in the wild, and chemical treatments involving immersion of collected *U. cinerea* and their host oysters in solutions of formalin, potassium permanganate, chlorol (10% chlorine), phenol (0.15% in seawater) and copper sulphate and also just freshwater (Hancock 1959; Spencer 1992).

The introduction of *Sargassum muticum* to southern England in 1973 and the subsequent failure to control the alga has been documented in detail by Critchley *et al.* (1986). The eradication attempt employed a large range of methods including handpicking, mechanical harvesting, treatment with various herbicides, and trials with native grazing molluscs (Critchley *et al.* 1986). Handpicking and shore-based mechanical harvesting of *S. muticum* were time-consuming, labour-intensive, and, despite large amounts of algae being removed, the efficacy was low and needed to be repeated. In addition, incursion sites were difficult to access, the shoreline was damaged by equipment, and collected material was difficult to contain and to dispose of (Critchley *et al.* 1986). Trawling and cutting equipment specifically developed for the removal of *S. muticum* were used, however the methods lacked species-specificity and caused considerable ecological damage. Native grazers consumed the target species, but, when given a choice, preferred other macroalgae. Grazing was also observed to lead to fragmentation of *S. muticum* thalli that may have lead to enhanced dispersal of the pest (Critchley *et al.* 1986).

3.2 Lesons from terrestrial pest eradication

There has been a much longer history of pest eradication in terrestrial than marine environments. Eleven case histories of varying duration (1 to >40 years) and varying success are discussed in Dahlsten and Garcia (1989) from which the editors concluded:

- Eradication campaigns are usually operated by large government agencies, physically removed from the project site leading to undue emphasis on administrative rather than biological and ecological components;
- Importance of distribution and abundance of pest de-emphasised, leading to lack of monitoring and lack of rational criteria for evaluation and action;
- Lack of research into many important potential pests has led to crisis management;
- Crisis management has led to overuse and over-application of chemicals;
- Over-reliance on chemicals by program administrators;
- Little effort made to identify and evaluate side effects of eradication efforts;
- Advice from scientific community sought only when agencies need support for their programs, leading to a lack of alternative viewpoints;
- Information provided to public typically represents agency's view only; and
- Once initiated, eradication programs have lacked appropriate critical evaluation and hence modification or termination of inappropriate methods.

Eradication is an appropriate response to an alien pest or potential pest, while the pest is restricted to a small area at some stage in its life. Eradication technologies need not be highly specific if their impacts on non-target species are limited to a restricted area. Once a pest has become more widespread, control techniques need to have higher specificity and be spread organically to reduce impacts on non-target species and to reduce costs. At some point, eradication becomes infeasible (using currently available technologies) and long-term control (Integrated Pest Management) becomes a preferred response to reduce the population to an economically or ecologically acceptable level and further maintain it at or below that level.

Measuring the success of long-term eradication or control campaigns can be complicated. For example the white-fringed beetle *Graphognathus* spp., an important agricultural pest, was first discovered in Florida in 1936. A Federal-State Cooperative Control Program was set up to eradicate or at least quarantine the pest to its then current range, using mass broadcasting of pesticides such as DDT and dieldrin (later banned due to environmental health hazards). The quarantine was officially terminated in 1975, when the beetle had spread almost to its ecological limits (Pitcairn and Manweiler 1989). The eradication and quarantine program can be considered a success because the spread of the pest was delayed, buying time and maintaining agricultural profitability. However, it was also a failure because the pest eventually spread throughout its ecological limits, and because of the high environmental costs due to the impacts of the subsequently banned chlorinated hydrocarbon pesticides.

4 MAKING THE DECISION TO ERADICATE

While it is possible to evaluate the success of an eradication or control program while it is underway or at completion, there is far less information available with which to evaluate the advisability (economic, environmental, social) of starting the program. One key uncertainty is whether the isolated alien pest population (presumably detected soon after establishing) will become a major pest. It has proven difficult to predict whether or when a species will become a pest (eg. Hengveld 1999; Moyle 1999). On the other hand many invasive species do not become major pests, disrupting their new ecosystem, but instead become accommodated in existing assemblages through niche shifts and other mechanisms or occupy degraded environments poorly suited for native species (Moyle 1999). When the ctenophore *Mnemiopsis leidyi* was first discovered in the Black and Azov Seas and linked to the crash of anchovy fisheries (Zaitsev 1992), an international group of experts recommended that biological controls including the release of alien generalist vertebrate predators be considered (GESAMP 1997). This could have had major impacts on the ecosystems of the Black and Azov seas and the adjoining seas, competing with similar native generalist gelatinous zooplankton feeders forming the basis for local fisheries. Soon after the GESAMP recommendations, abundances of *M. leidyi* had declined and planktivorous fish species had re-established (Shiganova 1998, Purcell *et al*, in press).

The decision to attempt eradication of an exotic pest will rarely be easy, requiring as it does the balancing of conflicting objectives in a social, political, and judicial complex in a low-information environment. Factors that can increase the probability of making the appropriate decision include:

- Knowing basic ecology and physiology of likely invasive pests;
- Early and accurate detection of a potential invasive pest;
- The ability to quarantine the area while eradication is being considered;
- Survey capacity to determine whether pest is restricted to quarantine area;
- Low risk of reintroduction;
- Pre-existing knowledge of available options for eradicating likely invaders and related taxa;
- Pre-existing decision making procedures and structures with powers to determine whether eradication should proceed, how and who should fund it;
- Sufficient technical, field, administrative, funding and legal resources to plan an eradication campaign;
- Ongoing monitoring to modify, amplify or end eradication campaign; and
- The willingness to act.

4.1 Rapid response decision-tree

Opportunities for a successful rapid response to a potential invasive marine pest may be improved if there is a clear decision and consultative procedure to follow. One attempt at producing a decision tree followed a 1998 Marine Conservation Biology Institute (MCBI) workshop on control of marine pests (Bax *et al.* 2001) and is reproduced here (Figure 1). The decision-tree is not specific to a particular species or location but could be updated to reflect best available information on ABWMAC species and related taxa.

The decision tree (Figure 1) consists of a series of "steps" to guide decision making on controlling an alien marine pest. These steps are part of an iterative, rather than linear process, with some steps repeated if additional information is necessary or if agreement is not reached. The flowchart also incorporates the role of regional stakeholders throughout the process: decisions made at various steps require value judgements to be made based on the best available science. This includes determining the severity of the problem to be addressed, the objectives to be achieved, the level of risk to take, and whether to proceed based on knowledge of risks and likely benefits. If such value judgements are to be representative of the wider community, they must involve the stakeholders affected by the alien species as well as those affected by proposed control options.

Step 1: Establish the nature and magnitude of the problem

There are several key questions to be addressed at this step. First, it is essential to confirm that the species is indeed an alien and not a locally rare or occasional species responding to an altered environment. This may require advanced genetic techniques, especially when only particular strains of a species are invasive. Second, it is necessary to determine the vector(s) that transported the alien species to its new environment and determine the risk that further invasions could occur. Third, the local and regional distribution of the species needs to be identified so that the areas requiring control are known. Lastly, preliminary estimates of the actual and potential impacts of the species and identification of potential control options are required before proceeding to regional stakeholder review.

It can take many years to progress to Step 2, especially in the marine environment where alien species may be hidden from view or overlooked as a local species until impacts become severe. The intertidal mussel *Mytilus galloprovincialis* was present on the South African coast for several years before it was recognised as alien by local researchers (Calvo-Ugarteburu and McQuaid 1998). Similarly *Asterias amurensis* was mis-identified as a local species in Tasmanian waters for almost a decade (Goggin 1998a) – it is now considered to be Australia's most damaging marine pest.

Control or eradication of an alien invasive species will be easiest, and in some cases may only be possible, at the earliest stages of an invasion. Given the difficulty of predicting potential impacts of an alien species, Crooks and Soulé (1999) suggest that when a species is locally contained and there is an opportunity to eradicate it with acceptable environmental consequences, extirpation should be early and vigorous. Underwater surveys and increased community education and awareness increase the chance that an alien invasive will be detected early on. A pre-existing management structure designed to lead the response to a detected (or suspected) alien invasive will accelerate progress to Step 2.

Step 2: Set and clarify objectives

Once the problem has been defined, regional stakeholders and decision-makers need to determine what they want to accomplish. Do they want to restore economic benefits lost? Do they want to restore or protect native biodiversity, endangered species, and ecosystem functioning? Do they want to address all of these problems? Is total eradication of the alien species desired, or is control to a certain level of abundance acceptable? What legal responsibilities must be addressed? And what are the performance criteria against which the success of any control program will be measured?

Step 3: Consider full range of alternatives

To address the problem and achieve the objectives, the full range of management options should be considered, including non-control options. Non-control options such as habitat improvement, pollution abatement, or improved fisheries management might be successful in restoring native biodiversity, ecosystem functioning, or economically valuable species. Such options may have lower risk than control options, and have secondary environmental benefits as well. They may, of course, take years to set in place.

Doing nothing is also a possible option. Populations of some terrestrial invaders have collapsed after their initial buildup. However, understanding the causes of these collapses could help predict the outcomes of future invasions as well as help in developing appropriate control procedures.

In considering control options, the level of control and the time period and area over which it is desired can assist in evaluating the relative merits of various options. For example, if a primary objective is ecological restoration, a risk-averse control program that reduces the ecological impact of the alien species to a state in which it no longer dominates the ecosystem over the long term might be suitable. Alternatively, if restoring economic benefits is considered an overriding objective, a more rapid and effective, but higher risk control program might be preferred. Also, many economic objectives might be limited in space since control may be necessary only in the areas under commercial development; eg. a mariculture farm. Any quick action, however, must be balanced against the need for adequate information to determine the nature of the problem, consider all options, and assess risk.

A successful control program typically will contain a suite of control activities including mechanical options, chemical treatments, biocontrol, and protection from reinvasion. Such Integrated Pest Management potentially allows managers to tie different control options to different areas, times, and life history stages in an effort to minimise the risks and costs while maximising the prospects for control.

Step 4: Determine risks

All control options contain risk. Risk is a function of the likelihood of harm occurring as well as the severity of the harm that results. The goal of successful alien species control is to effectively address the problems generated by the alien species while minimising the risk of undesired outcomes. Therefore, in considering the best suite of alternatives, the risks associated with each control option and the methods by which risks might be minimised should be determined. All risks are increased in the face of inadequate information. As specific control options are developed, continuing data collection and experiments will be necessary to improve knowledge on the likely impacts and constraints for the controls.

Step 5: Reduce risk

The first rule for reducing the risk of adverse results from control programs is to choose methods that are specific to the impact to be controlled. Specificity can be increased by limiting control to the identified pest or to a particular area or habitat; especially if that area or habitat is not unique and does not support threatened or endangered species.

Reducing risk includes proceeding with preferred alternatives on an experimental basis before full-scale implementation, and monitoring results to determine the efficacy and non-target effects of the approach. A preferred method of reducing risk is to use a control approach that is reversible, can be neutralised, or has only short-term effects.

There will be times, especially when responding to a recent invasion, that there is insufficient time to develop control techniques that are specific to the pest species. However, at the start of an invasion, the pest species is usually restricted to a small area. Risks can be reduced by acting promptly and accepting damage to this small area, so that a larger area can be protected (eg. the recent eradication of *Mytilopsis* sp.). Experimental application of control methods can be used as pilot-scale trials, and the outcomes used to reduce risk when control of the wider problem is attempted. Chemical controls used in eradicating *Mytilopsis* sp. were first tested in the laboratory and then in the smaller, recently excavated marina before being applied to all three marinas.

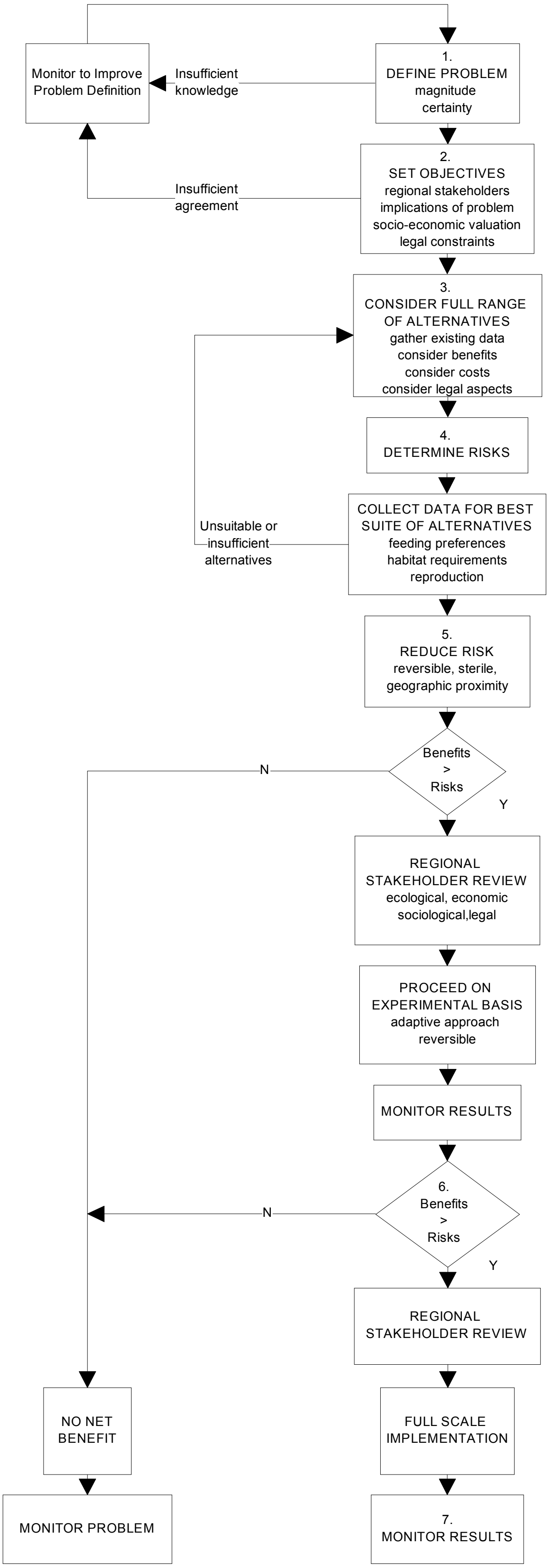

Figure 1. Rapid response decision tree

Step 6: Assess benefit/risk of full-scale implementation

The goals of a control program is to effectively control or eradicate the species, or otherwise address the problem, while minimising risk. However, evaluating alternative approaches, even after proceeding with steps 1 through 5 is not clear-cut. A useful tool for deciding whether to proceed with a program is to express the many inputs involved as an equation. A simple formula first suggested at the 1998 Marine Conservation Biology Institute (MCBI) workshop by Andrew Cohen of the San Francisco Estuary Institute is:

$$\text{Support for Control} = \frac{\text{Magnitude of Problem} * \text{Likelihood of Successful Control}}{\text{Magnitude of Adverse Result} * \text{Likelihood of Adverse Result} + \text{Cost of Control}}$$

This formula is essentially the benefit/cost ratio for a proposed control. The support for control will be high if the magnitude of the problem and the likelihood of successful control are high and/or the magnitude and likelihood of an adverse result and the costs are low. If this is the case then the control program is a candidate for proceeding. If the support is low, (ie. the magnitude and likelihood of an adverse result plus cost is high and/or the problem and likelihood of successful control are low) then the control program should not be undertaken. The formula is straightforward to apply when the magnitude of the problem and of an adverse result can be expressed in terms of their monetary value (although care needs to be taken to include both present and future discounted values). The formula is not straightforward to apply when environmental values that cannot be readily expressed in monetary terms are included.

The above formula was extended to account for the trade-off between monetary and environmental values when environmental values are not measured as monetary values (Box 1).A key parameter in the reorganised equation is β, a constant representing society's weighting of ecological and economic values. It is clear that presently there is no correct value for this parameter, although conceivably by applying the formula to existing environmental decisions, some idea of society's weighting of relative economic and environmental benefits and costs could be obtained. In a new area, such as the control of marine pests, it would be more appropriate to use the formula to explore the implications of alternative control options as an aid to understanding the full ramifications of particular choices. This is the case in a hypothetical application of the formula in Box 2.

Step 7: Monitoring

The commitment to and funding of a rigorous monitoring program should be a key component of any control or eradication program. Sufficient monitoring often has been lacking in terrestrial biological control programs and in marine environmental management in general. The control and eradication of alien marine invasions is in its infancy, and it is essential that programs be monitored to learn from early successes and failures. Monitoring will need to be rigorous, specific and targeted closely to the potential problem, and reported in the open literature.

Box 1. Decision Index: A tool for decision making (From Bax *et al*. 2001)

A useful means for sorting out and considering the many inputs involved in making the decision about whether to proceed with a control options is to express them as an equation. First, however, it is necessary to define the full set of terms:

a_1 = primary ecological benefit = $B_e \times P[B_e]$ or the product of the magnitude of the ecological benefit (environmental benefit of controlling the pest) and the probability of realising that gain.

a_2 = secondary ecological benefit = $B_{2e} \times P[B_{2e}]$ or the product of the magnitude of the secondary ecological benefits (environmental benefits in addition to those gained from controlling the pest) and the probability of realising that gain.

C_1 = ecological cost = $C_e \times P[C_e]$ or the product of the magnitude of ecological costs (side effects of the control) and the probability of realising that cost

b_1 = primary economic benefit = $B_\$ \times P[B_\$]$ or the product of the economic benefits (economic benefit of controlling the pest) and the probability of realising that gain.

b_2 = secondary economic benefit = $B_{2e} \times P[B_{2\$}]$ or the product of the magnitude of secondary economic benefits (economic benefits in addition to those gained from controlling the pest) and the probability of realising that gain.

C_2 = economic cost = $C_\$ \times P[C_\$]$ or the product of the economic costs (side effects of the control) and the probability of realising that cost.

C_3 = economic cost = $T + M$ or the direct costs of control and monitoring.

β = a constant representing society's weighting of ecological and economic values. A high beta means that economic values are greater.

These terms are combined in a proportionality to develop a decision index or benefit-cost ratio. Economic costs and benefits are separated from ecological costs and benefits, so that the proportionalities are not constrained by having to express economic and ecological factors in the same units. If the index is high, proceeding with the control is favoured; if low, the control is probably ill advised. Thus:

$$I = \left(\frac{a_1 + a_2}{C_1} \right)^{\beta} \times \left(\frac{b_1 + b_2}{C_2 + C_3} \right)$$

According to the formula, going ahead is favored (high I) if the problem is large and the probability of successful control (a_1 and b_1) are high. Not proceeding (low I) is suggested if the severity of damage from control and its probability (C_1 and C_2) are high. If society places a high value on economic as opposed to ecological values (low β), desirability of going ahead with a proposed control would be reduced if treatment and monitoring costs (C_3) were high, but increased if there were substantial secondary economic benefits (b_2 high). Secondary benefits will often be 0, but could be significant in situations where the control action may have ecological value, for example habitat improvement, or economic value, for example if a control fish became the subject of a commercial or sport fishery. If ecological values were relatively more important than economic ones (high β), then desirability of proceeding would increase with potential ecological benefits but decrease if potential ecological damage (or costs) were high.

Box 2. Application of the decision index to an invasive marine mussel (From Bax *et al*. 2001)

Here we apply the decision index developed in Box 1 to a hypothetical example very loosely based on the black striped mussel eradication in Darwin in 1999. While some of the values relate to that eradication, others are entirely hypothetical.

We use the decision index to explore the benefits and costs of three possible scenarios for the invasion of an exotic marine mussel. The mussel is assumed to have severe environmental and economic consequences on the marine environment and infrastructure in tropical Australia including reducing income of a $250 million pa pearl oyster fishery by 10% and annual engineering and cleaning costs of $50 million. Economic values are net present values assuming a discount rate of 10%. Environmental values are qualitative values between 0 and 1, based on the magnitude and extent of an impact or benefit. The three scenarios are:

1. The mussel is locally contained in an enclosed marina with minimal environmental value; chemical treatment is possible with some disruption to local businesses;
2. The mussel has escaped local containment, but is still restricted to a larger open port; chemical treatment is still a possibility but economic disruption and ecological damage will be high;
3. The mussel is locally contained in an already degraded environment; habitat restoration is being considered as a mechanism to reduce local impacts of the mussel. Local control will do nothing to reduce impacts on regional resources (the pearl oyster fishery) or infrastructure.

A value of β ranging from 3 to 1/3 was used to compare the decision index between scenarios (continuation of text box on next page). There is no correct value for $\tilde{\beta}$. In this hypothetical instance, it can be seen that scenario 1 has a high benefit to cost ratio (239-5325) regardless of the value of β, because both the economic and environmenal benefit/cost ratios are positive (3.2 and 162, respectively). The economic benefit/cost ratio is high because although the probabilities of realising the primary economic benefit and damage are the same (0.80), the primary economic benefit from preventing impacts on the pearling industry and infrastructure is high, while the potential economic damage is low ($2 million). Potential environmental benefits are high (0.80) because the eradication is designed to eliminate impacts on all regional habitats and biodiversity, while environmental damage is low (0.2) because it is restricted to a small area containing no threatened species.

Scenarios 2 and 3 are more interesting, because only one of the two benefit/ cost ratios is positive. Economic benefits are reduced in scenario 2 because of the reduced probability (0.20) of attaining those benefits once the mussel has spread outside the closed marina. At the same time treatment and monitoring costs are increased to $50 million. The environmental benefit/cost ratio is also less than scenario 1, because of increased environmental damage resulting from a wide spread chemical treatment (0.50 vs 0.20), and decreased probability (0.20) of attaining the environmental benefits. The decision index indicates that only when economic benefits are seen to have greater value to society relative to environmental benefits ($\beta < 1$) could scenario 2 be considered.

In contrast under scenario 3, the probability of realising the primary economic benefits is minimal (0.01) and magnitude of primary environmental benefits is small (0.10) because it is restricted to the locally degraded environment rather than regional habitat and biodiversity. It is only the potential secondary environmental benefit from habitat remediation (0.20) that leads to a postive decision index, and then only when the index is weighted to favour relative environmental benefits ($\beta > 1$).

Box 2. continued

Hypothetical probabilites defined for three scenarios used to explore the value of the benefit-cost index that would lead to action being taken.

Factor		Scenario 1	Scenario 2	Scenario 3
Primary environmental benefit	B_e	0.80	0.80	0.10
Probability of realising benefit	$P[B_e]$	0.80	0.20	0.50
Secondary environmental benefit	B_{2e}			0.20
Probability of realising benefit	$P[B_{2e}]$			0.80
Environmental damage	C_1	0.20	0.50	0.20
Probability of environmental damage	$P[C_1]$	1.00	0.80	0.20
Primary economic benefit	$B_\$$	731.23	731.23	731.23
Probability of realising benefit	$P[B_\$]$	0.80	0.20	0.01
Secondary economic benefit	$B_{2\$}$			
Probability of realising benefit	$P[B_{2\$}]$			
Economic damage	C_2	2.00	20.00	68.62
Probability of econmic damage	$P[C_2]$	0.80	0.80	0.80
Treatment and monitoring costs	C_3	2.00	50.00	5.00
Computed economic benefit/cost ratio		162.49	2.22	0.12
Computed environmental benefit/cost ratio		3.20	0.40	5.25

Acceptability Index

	beta			
↑ Economic value ↓	0.3	239.5	1.6	0.2
	0.5	290.7	1.4	0.3
	1.0	520.0	0.9	0.6
	2.0	1663.9	0.4	3.4
Environmental value	3.0	5324.6	0.1	17.7

5 CONTROL OPTIONS FOR TARGET TAXA

5.1 Toxic phytoplankton (*Alexandrium catenella, Alexandrium minutum, Alexandrium tamarense* and *Gymnodinium catenatum*)

Harmful algal blooms (HABs) caused by toxin producing strains of phytoplankton occur globally. Countries reliant on coastal aquaculture (eg. Korea, Japan, and China) have been particularly active in researching HABs. Much of the research has focused on monitoring and impacts of HABs in order to protect public health, fisheries resources, aquaculture, ecosystem structure and function, and coastal aesthetics (Gross and Enevoldsen 1998). The growth and accumulation of a harmful algal species is a complex process involving chemical, physical and biological interactions – toxic blooms are therefore a phenomenon of the plankton community not just a single species. Modelling bloom occurrences is difficult and there have been very few models examining marine HABs as a community phenomenon (Gross and Enevoldsen 1998).

Strategies to reduce bloom impacts include preventing formation of the blooms, avoiding use of areas where blooms are present and minimising their affect. Current control methods attempt to alter the size, composition or duration of the bloom either directly by targeting an existing bloom, or indirectly by trying to reduce future blooms (Gross and Enevoldsen 1998). Most control techniques are taxa-specific rather then species-specific. For example, a method to control *Alexandrium catenella* is most likely suitable for other phytoplankton species (or at least for dinoflagellates). Increased nutrient loading in coastal waters, primarily nitrogen and phosphorus, has been linked to increased algal blooms. Common examples include the Seto Inland Sea in Japan, Tolo Harbour in Hong Kong and the Baltic and North Seas in Europe (Rensel and Martin 2000). Mitigating HAB effects may require improving coastal water quality, through improved sewage treatment and reduced nutrient run-off from surface drainage, agricultural chemicals, etc. (Whyte *et al.* 1997).

Two main approaches have been mooted to prevent or control cyanobacterial blooms in freshwater. The first is a ‘bottom up” approach in which the supply of essential nutrients is restricted. The second is a ‘top down’ or ‘biomanipulation” approach in which attempts are made to restructure the food web to maximise consumption of noxious cyanobacteria by herbivorous zooplankton, particularly large cladoceran crustaceans (Boon *et al.* 1994; Gehrke and Harris 1994; Matveev *et al.* 1994). Intermittent destratification has been used in enclosed freshwater systems to decrease phytoplankton biomass while not altering successional patterns (Simmons 1998).

5.1.1 Physical control

Physical methods for controlling HABs in the marine environment include: changing local water circulation to prevent local eutrophication of poorly flushed waters; destratification of the water column by vertical convection, aeration or pumping to inhibit growth of plankton requiring calm stratified and/or warmer water; the use of clay flocculants to precipitate out plankton and/or nutrients that adhere to the particles; and ultrasonic vibrations to destroy plankton cells (Berdalet and Estrada 1993; Gross and Enevoldsen 1998; Whyte 1999). Clay flocculants, ultrasonic vibrations and chemicals could be useful in rapid response to invasive marine plankton and are discussed in more detail here.

Flocculants such as clay (particle size <2μm) trap other particles including phytoplankton from the water column, causing deposition to the bottom. Clay flocculants have removed 90-99% of phytoplankton with little detectable impact on larger life forms (Sengco *et al.* 2001) and have been used to protect fish farms in Korea and Japan (Rensel and Martin 2000; Zhiming *et al.* 2000). Margot Higgins (M. Sengco, Woods Hole Oceanographic Institution, US; pers. comm.) has used clays to remove phosphates and thereby reduce bloom intensity in Australia. Sengco *et al.* (2000) examined the flocculation and sedimentation of 26 mineral clays on four toxic algal species. Clays that removed one species were not always effective on other species. For *Ptychodiscus* (*Gymnodinium) breve* and

Heterosigma akashiwo, 80-90% cell removal could be achieved with loadings as low as 30ppm. Surfactants such as polyhydroxy aluminium chloride (PAC) reduced the loading needed for cell removal by nearly an order of magnitude.

Further research is required on the fate and effects of sedimented cells, toxins and aluminium-clay compounds on the benthos and the disruption to other co-occuring plankton species (Gross and Enevoldsen 1998). HAB organisms and associated toxins deposited in the sediments may be incorporated back into the food chain by benthic organisms. For this reason the dispersal of toxins using a method that destroys the algal cells is preferred over one that deposits them in the sediments.

Clays can both release and remove important algal nutrients (nitrates, phosphates and silicates) in the water column; the release can be moderated considerably by the addition of small amounts of PAC (Sengco *et al.* 2000). However, altering nutrient availability may cause a shift in the microalgae community eg. the new environmental conditions may favour introduced species over native species leading to greater impacts than the original bloom (Imai 1997; Lovejoy *et al.* 1998).

A new invention called Aquasonic kills all kinds of algae and prevents reinfestation by transmitting ultrasonic vibrations through the water causing algae cells to implode and die. Most algae are killed within 48 hours but filamentous algae may take a couple of weeks. There are devices for water ponds from 2-150 metre diameters. Since 1997, 2000 Aquasonic units have been installed in The Netherlands and Belgium, mainly in freshwater water reservoirs used by market gardens (Thomas and Gerritsen 2000).

Montani *et al.* (1995) trialed electric shock as a treatment method to control toxic dinoflagellates in ballast water but Hallegraeff *et al.* (1997) concluded that the effectiveness of the method was due to the production of chlorine through electrolysis.

5.1.2 Chemical control

Chemical control options have received little attention for controlling HABs in recent times because the chemicals have low specificity, impacting on many different taxa. It is also difficult to apply and maintain sufficient concentrations in open areas covered by an algal bloom. Chemicals previously trialed as control agents for toxic algal blooms include copper sulphate, hydrogen peroxide, chlorine and pesticides.

A study in Florida in 1964 screened 4306 “off the shelf” chemicals for use against a red tide alga and found 250 resulted in death of the alga at concentrations of 0.4 ppm. However, the cost of many was prohibitive and there has been no follow-up research (Marvin and Proctor 1964 as cited in: Martin and Taft 1998). Kutt and Martin (1974) reported that anionic surfactants caused 90% mortality when applied to cultures of *Ptychodiscus breve*.

The first large-scale attempt at chemical control of a red tide of *Ptychodiscus breve* was made forty years ago. Twenty pounds per acre (22kg per hectare) of copper sulphate was applied by crop dusting planes to about 16 square miles of sea, stretching along 32 miles of coastline in Florida. Alga cell counts were quickly reduced to close to zero but rose back to high concentrations in less than two weeks. The method was not recommended for general control as it was deemed too expensive and non-specific and caused general environmental damage (Rounsefell and Evans 1958). Marvin (1960) demonstrated that copper sulphate when applied at concentrations between 0.39-0.80µm of copper ions produced 100% mortality of *P. breve* but it was later concluded that because of its low solubility, copper sulphate ore could not be used as an effective control measure (Rounsefell and Nelson 1966).

The effect of hydrogen peroxide on toxic phytoplankton has also been examined (Miyazaki *et al.* 1990; Ichikawa *et al.* 1993). Hydrogen peroxide is absorbed by porous granules of calcium silicate and released in water. It decomposes into water and oxygen over time, with 30% decomposing in 48 hours and 70% in 96 hours. *Gymnodinium nagasakiense* was destroyed within 30 minutes of application of porous granules containing hydrogen peroxide at concentrations as low as 4.5-6 mg l^{-1}

(Miyazaki *et al.* 1990). In contrast, several fish species suffered no mortality after a three minute exposure to 300, 900 or 1500 mg l^{-1} concentrations. Cysts of *Alexandrium catenella* and *A. tamarense* died at concentrations of 30 mg l^{-1} of hydrogen peroxide after 48 hours exposure and all cysts were destroyed (no germination occurred) after exposure to 100 mg l^{-1} for 96 hours (Ichikawa *et al.* 1996). Hydrogen peroxide has been proposed for use in ballast tanks where cysts and motile cells can be effectively killed within several days and the hydrogen peroxide decomposes to become harmless to the environment. However, hydrogen peroxide is very corrosive and probably unsuitable for ship ballast water tanks. There are no studies on the use of hydrogen peroxide on cysts in the natural environment.

Chlorination is often used in closed freshwater systems to control phytoplankton blooms (Boyd 1996), but would be impractical on a large scale in open ocean situations because of the amounts of chlorine required. It has been used to control biofouling organisms in power station cooling waters and was found to produce large decreases in the productivity of entrained marine phytoplankton (Carpenter *et al.* 1972). Laboratory studies have found that NaOCl at concentrations of 0.5 ppm produced by electrolysis of natural seawater rapidly reduced populations of five red tide dinoflagellates including *Gymnodinium sanguineum*. Ciliates and copepods were not affected and half the NaOCl degraded to NaCl within 2 hours in bright sunlight (Kim *et al.* 2000).

Addition of the common fertiliser component, ammonium sulphate at a concentration of 1:100 000 to brackish water ponds in Israel caused mortality of the toxic alga *Prymnesium parvum,* with generally no adverse effects on fish or other plankton. Liquid ammonia is reported to be a useful and inexpensive control agent at temperatures lower than 20 °C and < pH 8.5 (Kimor 2000). The effects of herbicides, fungicides and insecticides in freshwater algae, particularly on cyanobacteria and green algae were reviewed by Venkataraman *et al.* (1994). Depending on the type, biological property and concentration of pesticides and the algal strain exposed, their effect could be inhibitory, selective or even stimulatory.

5.1.3 Management of spread and translocation

A variety of chemical and physical treatment options capable of killing and/or removing toxic dinoflagellate (*Gymnodinium catenatum* and *Alexandrium spp.*) cysts in ships' ballast water have been trialed (Hallegraeff 1998). These methods are summarised in Table 1. They are not readily applicable to the sediments in the natural environment and no methods of removing the cysts from the sediment were found in the literature.

The CRC Reef Research Centre and the Ports Corporation of Queensland conducted a comprehensive review of ballast water management options over three years, including ballast exchange, ship-board treatments and disinfectant technologies both chemical and physical (Oemcke 1999). The majority of these treatments have been shown to be ineffective, unsafe, too costly or environmentally damaging for long term or widespread use. Exchange of ballast water is currently the only option available to shipping, although heat treatment of ballast water shows some promise (Rigby *et al.* 1999).

Some algae can survive inside bivalves being transferred to a new location. The dinoflagellates *Alexandrium minutum* and *A. tamarense* have survived passage through the gut of oysters and remained viable and regained their motility after 24 hours, while *Gymnodinium mikimotoi* did not survive gut passage. Similarly, viable cells of *A. fundyense* were egested by *Mytilus edulis* and continued their growth (Bricel *et al.* 1993). The survival of algae in bivalves increases the risks of being transferred to virgin areas through the movement of stocks between farms (Laabir and Gentien 1999); stricter controls on translocation of shellfish from areas containing HABs would reduce this risk.

Table 1. Chemical and physical treatments trialed on toxic algal cysts and vegetative cells in ballast water.

Treatment method	Citation
Ballast water exchange/ Reballasting	Hallegraeff and Bolch 1992; Rigby and Hallegraeff 1994; Dickman and Zhang 1999; Zhang and Dickman 1999;
Changes to pH or salinity	Bolch and Hallegraeff 1993
Chlorine	Bolch and Hallegraeff 1993; Montani *et al.* 1995
Copper sulphate	Bolch and Hallegraeff 1993
Electric shock/ electrolysis of seawater to produce chlorine	Montani *et al.* 1995; Hallegraeff *et al.* 1997
Heat treatment	Montani *et al.* 1995; Bolch and Hallegraeff 1993; Hallegraeff *et al.* 1997; Rigby *et al.* 1999; Mountfort *et al.* 1999a
Hydrogen peroxide	Bolch and Hallegraeff 1993; Ichikawa *et al.* 1993; Montani *et al.* 1995
Microbiocide “Kathan WT”	Bolch and Hallegraeff 1993
Oxygen deprivation	Mountfort *et al.* 1999b
Ultraviolet radiation	Montani *et al.* 1995; Morgan *et al.* 1999

5.1.4 Long-term control and management

Aquaculture

Predicting the threat of a bloom and taking appropriate action can minimise the effects of HABs in aquaculture: fish cages can be transported to deeper water, refuge sites or more brackish waters; stationary pens can be made deeper or can be constructed in a manner that allows pens to be lowered during a surface bloom; fish or shellfish can be harvested early; and quality and volumes of fish food can be modified to reduce available nutrients. Skirts of plastic barriers around the perimeter of pens enables upwelling of deeper colder water either by aeration or using airlift or hydraulic pumps. This prevents the advection of surface algal blooms into the pens, reduces anoxic conditions caused by the algae and can inhibit algal growth by lowering water temperatures (Taylor 1993; Whyte 1999).

Preventative actions include basing the siting of aquaculture facilities on hydrodynamics, water quality and prevalence of algal cysts in the sediments; or selecting aquaculture species that are less susceptible to particular HABs. Knowledge of regional bloom dynamics identifies the conditions that produce a bloom so that evasive action can be taken quickly. Eutrophication has been implicated as a factor causing blooms, but before control strategies to reduce nutrient inputs are implemented the source of nutrients must be determined (Gross and Enevoldsen 1998). Dredging in Tasmanian State waters is prohibited without approval, under the Environmental Management and Pollution Control Act 1994 and the Living Marine Resources Management Act 1995, to reduce the re-intrainment of cysts into the water column and prevent triggering a bloom. Toxin levels in commercial shellfish are monitored under the Tasmanian Shellfish Quality and Assurance Program.

Biological control

Longer-term control options include biological control agents such as parasites and predators, the use of natural chemicals produced by other marine organisms (allelopathy) and biomanipulation. Parasites of toxic phytoplankton include viruses (Milligan and Cosper 1994; Nagasaki *et al.* 1994; Bratbak 1996), bacteria (Furuki and Kobayashi 1991; Lovejoy *et al.* 1998; Doucette *et al.* 1999), fungi (Mountfort *et al.* 1996), protozoans and other dinoflagellates (Taylor 1968; Wakeman and Nishitani 1982; Delgado 1999; Erard-Le Denn *et al.* 2000a, 2000b). Some of these parasites have profound impacts on HAB population dynamics in nature and are promising control agents (Gross and Enevoldsen 1998). The parasitic protozoan *Parvilucifera infectans* has infected and killed the toxic dinoflagellates *Dinophysis* and *Alexandrium* in Scandinavian waters. A similar parasite has been found infecting *A. minutum* cells in French estuaries (Erard-Le Denn *et al.* 2000a, 2000b) and a “diablillo” parasite has recently been found infecting *A. catenella* in a bloom in Spain (Delgado 1999). The *Parvilucifera* parasite shows two of the prerequisites needed for a control agent: high efficiency of lethal infection and the potential to be cultured on a large scale. Use of algal parasites is still hypothetical and considerable research is needed to determine their usefulness and methods for their application as potential biocontrol agents (Gross and Enevoldsen 1998, Noren *et al.* 2000).

Native populations of predators of toxic dinoflagellates could be enhanced to control blooms. Grazing by copepods, cladocerans, fish larvae and adults, and microzooplankon such as rotifers, ciliates and heterotrophic dinoflagellates is believed to contribute to the decline of algal blooms (Gehrke and Harris 1994; Jeong and Latz 1994; Matveev *et al.* 1994; Teegarden and Cembella 1996; Turner and Tester 1997; Matsuoka *et al.* 2000). Filter feeders (primarily mussels *Mytilus edulis* on rope collectors) can filter phytoplankton out of the water column during blooms, where the algal cells enters the sediment bound to detrital matter (Takeda and Kurihar 1994). Once safely depurated these mussels could be sold as a commercial crop. The bivalves, *Mercenaria mercenaria* have also been shown to control the initiation of brown tides of *A. anophagefferens,* by exerting grazing pressure at low cell densities of this alga. Once algal densities rise too high, bivalve feeding rates are suppressed and bivalves close (Caron and Lonsdale 1999a, 1999b; Rensel and Martin 2000). The freshwater mussel *Dreissena polymorpha* has the potential to be used to reduce phytoplankton blooms in the water column (Welker and Walz 1998). A second level filter, using sea cucumbers on the sediment surface ensures that the mussel flocculant is consumed and hence the algal cells enters the sediment bound to detrital matter; its fate after this could be of concern if it the toxins enters the food chain through predation on the sea cucumbers (Takeda and Kurihar 1994). Toxic plankton such as *Gyrodinium aureolum* and *Aureococcus anophagefferens* are known to decrease filtration rate and cause changes in physiological and cytological conditions in *M. edulis*, resulting in mass mortality of the mussels (Takeda and Kurihar 1994). However *M. edulis* could be used to control aesthetically unpleasing blooms of non-toxic phytoplankton in tourist areas.

Ptychodiscus breve could be managed in localised areas through the use of natural chemicals produced by other marine algae. The allelopathic chemical (aponin) produced by the blue-green algae *Gomphosphaeria aponina* is cytolytic towards *P. breve* (Kutt and Martin 1975). The thermal stability and rate of degradation of aponin in seawater make it economically and environmentally suitable. The most likely prospect for control of *P. breve* by *G. aponina* is through conditioning of the water mass by the blue-green algae preceeding or during a red tide bloom. Rapid proliferation of *Gomphosphaeria aponina* (known to occur in cultures of *P. breve*) would cause *P. breve* to revert to a sessile form or to the destruction of cells by the cytolytic action of the aponin (Eng-Wilmot and Martin 1978; Martin and Taft 1998). The green algae *Nannochloris oculata* and *N. eucaryotum* have also been shown to contain aponins that inhibit the growth of *P. breve* (Perez *et al.* 1997).

Growth of *Alexandrium tamarense* and *Cochlodinium polykrikoides* was inhibited by extracts from the red macroalga *Corallina pilurifera* (Hong 1997).

5.1.5 Summary

There are several promising approaches that are being used and several more that could be developed to control HABs in the water column. However, no method for removing spores/cysts from the sediment has been suggested in the reviewed literature. The parasite species discussed above only infect motile cells and resting cysts are not affected. This highlights the difficulties in achieving the total destruction of harmful algae populations in natural environments. Until this can be addressed the eradication of introduced phytoplankton species is an unrealistic goal.

Long term control of blooms may lead to an effective reduction in cyst concentration to low levels. A fundamental lack of understanding of the environmental factors causing phytoplankton species to bloom (Donaghay and Osborn 1997) means that controls can be effectively instigated only once a bloom is underway. Further research to determine the actions that would reduce the likelihood of a bloom occurring is required.

5.2 Macroalgae (*Undaria pinnatifida*, *Codium fragile* ssp. *tomentosoides*, *Caulerpa taxifolia* and *Sargassum muticum*)

Four macroalgal species have been identified as being of worldwide concern as potential pest species: *Undaria pinnatifida*, *Codium fragile* ssp. *tomentosoides*, *Caulerpa taxifolia* and *Sargassum muticum. U. pinnatifida* has been present in Australia since the 1980s and is listed as a target pest species on the 1995 ABWMAC pest list. *C. fragile* ssp. *tomentosoides* was found in Australia in 1996 and is listed on the 1999 Interim Pest List produced by the Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions. Also on the Interim Pest List are the so-called aquarium strain of *C. taxifolia*, which is assumed to have invaded the Mediterranean, and *S. muticum*. *C. taxifolia* is a native alga along the Australian tropical and subtropical pacific coast. To date, there have been no reports of introduced strains of *C. taxifolia* in Australian waters (Schaffelke et al. *in press*). *S. muticum* has also not been found in Australian waters, however, this species has been a problem in many other parts of the world. Control measures and management options for *U. pinnatifida* and *S. muticum* in Europe are discussed by Wallentinus (1999a, 1999b).

Caulerpa taxifolia first appeared in the Mediterranean in 1981. The total eradication of *C. taxifolia* “is no longer a realistic objective” given its current large extent (Gravez *et al*. 1999). The recommended management strategy includes: documentation of the spread and ecology of *Caulerpa taxifolia*; prevention of domestic and international translocation; preservation of high value areas; and control of existing colonies to slow down spread.

Any response option must take into account the capability of some introduced macroalgae to reproduce asexually from fragments (*Caulerpa taxifolia*: Ceccherelli and Cinelli 1999, Smith and Walters 1999; *Codium fragile* ssp. *tomentosoides*: Trowbridge 1999). Other species have microscopic lifestages that are cryptic and difficult to target (*C. fragile* ssp. *tomentosoides* and *Undaria pinnatifida*). Additionally, thalli with mature propagules, which may become detached by control techniques, may contribute to enhanced translocation of these species (Wassmann and Ramus 1973 for *C. fragile* ssp. *tomentosoides*; Paula and Eston 1987 for *Sargassum* species; Sliwa 1999 for *U. pinnatifida*).

5.2.1 Physical control

Manual removal of *Caulerpa taxifolia* in a National Park in the French Mediterranean is reported to have successfully eradicating the alga from the treated area (Cottalorda *et al*. 1996, Thibaut 2000). The eradication was initiated at an early stage of invasion in 1994 (area covered by *C. taxifolia* colony: 3.4 m^2). The method used was careful removal of thalli and fragments by Scuba divers; the site was then regularly monitored and the removal was repeated, as necessary (Cottalorda *et al*. 1996). A mathematical simulation, using *C. taxifolia* expansion rates from other areas, predicts that without early eradication this small colony would have expanded to an area of more than 2 hectares over 4 years (Thibaut 2000).

Two accounts of total and partial removal of *Caulerpa taxifolia* have been reported from Croatia (Zuljevic and Antolic 1999a, 1999b). Actions included removal of fragments with a suction pump (treated areas 350 and 250 m^2, respectively), and covering a larger patch with black PVC plastic (treated area 512 m^2). Re-surveys of the areas showed no or only sporadic regrowth *of C. taxifolia*. The estimated effort in these three case studies was the clearance of an area of <1 m^2 to ~3 m^2 per diver per hour.

Repeated removals of *Caulerpa taxifolia* at a site ~ 2 hectares in the Spanish Mediterranean have not eradicated the alga but significantly decreased the abundance and controlled the spread to adjacent areas (Grau *et al*. 1996). Plants were removed by scuba divers and a suction pump was used to remove fragments. The area was monitored regularly and treatment repeated, as necessary over 2 years (Grau *et al*. 1996). The effort is estimated to have taken ~ 550 dive hours at an approximate cost of 383 ECU m^{-2} (Boudouresque *et al*. 1996).

Manual removal of *Undaria pinnatifida* (by scuba divers) was attempted at the Tinderbox Marine Reserve, Tasmania (C. Hewiit and B. Schaffelke, CRIMP; pers. comm.), Port Phillip Bay, Victoria (S. Campbell, EPA Victoria; pers. comm.), and Big Glory Bay and Bluff Harbour in New Zealand (M. Stuart, DOC New Zealand; pers. comm.) In Tasmania and Victoria, eradication of *Undaria* was not achieved. However, the removal at Tinderbox resulted in a significant reduction in sporophyte abundance in removal transects compared to untreated control transects (Hewitt *et al*., in prep.). The ongoing eradication program in New Zealand is concentrated on removing *Undaria pinnatifida* from defined areas of high value or intense vessel traffic (Stuart 2000). In this program, which costs ~NZ$0.5 million pa, sporophyte numbers have been notably reduced, and removal efforts in ensuing years are likely to be lower. The program also includes vessel monitoring and cleaning if necessary and an assessment of the costs and benefits of the total effort. At a national level, however, *Undaria pinnatifida* populations in New Zealand are still expanding.

Trowbridge (1999) discusses two unpublished trials of manual removal of *Codium fragile* ssp. *tomentosoides*. Considerable regrowth of the alga occurred in both cases. A particular problem for the physical removal of *C. fragile* ssp. *tomentosoides* in Australia is the difficulty in distinguishing introduced from native subspecies without microscopic examination.

Although mechanical removal has worked in a number of cases, general application of this technique is constrained by the high costs. Experience has shown that it is critical to involve workers that are specifically trained for the response option because:

1. They need the competence to identify the target species;
2. They need to be able to carry out the removal in accordance with appropriate health and safety regulations,
3. They need to be informed about possible damage to non-target organisms or habitat and how to avoid it.

Case studies with partial or complete success of removal of target species often concentrated the effort on defined areas of high value, such as marine parks. In these areas, manual removal may be considered the preferred response option assuming that collateral damage can be kept to a minimum.

Commercial harvest has often been proposed as a management option (eg. Critchley *et al*. 1986, Hay and Luckens 1987, Boudouresque *et al*. 1996). Macroalgae are used either as food (eg. *Undaria pinnatifida* as the sea vegetable ‘Wakame’) or as raw products for extraction of compounds (alginate, secondary metabolites, and organic compounds used as fertiliser or as an ingredient of animal food).

The main concern associated with mechanical removal techniques is regrowth from microscopic stages that are not removed (vaucherioid stage of *Codium fragile* ssp. *tomentosoides*, gametophytes of *Undaria pinnatifida*, holdfast remnants of *Sargassum muticum*) or from fragments produced by the removal (*Caulerpa taxifolia*, *C. fragile* ssp. *tomentosoides*). Also, small recruits of target species are likely to be overlooked due to difficulties in finding, identifying, and actually removing them. A successful removal strategy would use suction to remove fragments produced while harvesting, and regular monitoring after the first removal so that follow up removals can be planned as necessary.

Mechanical removal techniques such as dredging may cause substantial damage to non-target species and habitats. They are also difficult to implement as most infestations occur in shallow water. Mechanical techniques are less targeted than manual removal and are more likely to result in thallus fragmentation and hence increased dispersal of the target species.

The success of commercial kelp harvesting devices to remove *Undaria pinnatifida* is doubtful because this annual kelp produces fertile sporophytes throughout the growth season instead of for a narrowly defined period as in other kelps. Mechanical harvest would likely lead to fragmentation of harvested sporophytes or to residual stipes with fertile sporophylls, both of which are likely to increase dispersal. In addition, commercial harvesting would not normally deplete a population below economically sustainable levels. When harvested for human food, in general only large thalli of healthy appearance are selected, other individuals are left in place. The toxic secondary metabolites in *Caulerpa taxifolia* and *Codium fragile* ssp. *tomentosoides* possibly prevent the use of these algae as animal fodder. They may, however, contain useful bioproducts (Boudouresque *et al.* 1996).

The use of blue light to induce gametogenesis, followed by collection of the plants over an extended period has been suggested as a method to trigger enhanced growth of *Undaria pinnatifida* sporophytes from the gametophyte reservoir (J. Bité VUT, Victoria; pers. comm.). However, blue light also triggers gametogenesis in other Laminariales (Lüning 1980), including the co-occurring species *Macrocystis pyrifera* and *Ecklonia radiata*, and the critical blue light quantum dose for gametogenesis of *U. pinnatifida* is higher than that of other kelps (Stuart 1997).

Dry ice damaged *C. taxifolia* in an aquarium experiment, however in the field only sublethal necroses were caused (Boudouresque *et al.* 1996). The *in situ*-application of ultrasound was also unsuccessful. Underwater application of hot water at or above 40ºC at the plant surface resulted in destruction of *C. taxifolia*, however, recovery was observed after 3 weeks.

In situ-heat application has been successfully used to kill *Undaria pinnatifida* gametophytes on a ship's hull (Mike Stuart, pers. comm.). A wooden box with heating elements was attached to the hull and heated the enclosed water volume to about 70ºC, resulting in 100% gametophyte mortality.

Other mechanical techniques that have been suggested include blanket-blasting and covering infested areas with dredge spoil to smother plants, blocking off light and also causing physical damage. Control programs involving physical burial of invasive macroalgae would have to be carefully designed because of the potential to cause significant environmental damage and improve the habitat for settlement and expansion of other introduced species. In Japan, blanket blasting and deposition of stones on the sea floor are techniques used to increase the substrate surface area and hence increase the crop of *Undaria pinnatifida* (Tseng 1981).

5.2.2 Chemical control

The toxicity to macroalgae of a number of substances has been studied, in particular copper sulphate (or other copper compounds), various commercial herbicides, antifoulants, chlorine, and lime.

Herbicides, copper sulphate, sodium hypochlorite and phytohormones have been trialed against *S. muticum* in England and France. While certain products (ie. copper sulphate), have proved effective, their low specificity and persistence in the environment make them unsuitable for use (Belsher 1991; Ribera and Boudouresque 1995).

Much of the total copper concentration in seawater is chelated (Sunda and Guillard 1976) and not available. Copper ion toxicity to plankton is well studied – it is concentration dependent, and causes damage to cell membranes, disrupts photosynthesis and eventually causes death (Sorentino 1979). Concentrations of copper ions of >10 μg l^{-1} had detrimental effects on growth, development and morphology of kelp, with different life stage showing different sensitivity (Brinkhuis and Chung 1986, Chung and Brinkhuis 1986). In contrast, concentrations of 10 and 50 μg l^{-1} led to increased copper storage in *Ascophyllum nodosum*, a fucoid alga, but did not affect growth or fitness (Toth and Pavia 2000).

Copper ions have been applied to *Caulerpa taxifolia* using a range of different application methods. The success of the techniques was variable – in most cases aquarium tests had promising results, but field application was often difficult or unsuccessful (eg. Boudouresque *et al.* 1996). The effect of copper depends on concentration and application time. Laboratory experiments have shown a copper-ion concentration of >10 ppm (= 10 mg l^{-1}), applied for 30 minutes, causes complete mortality of *C. taxifolia* (Uchimura *et al.* 1996). Copper ion concentrations required to obtain 100% mortality were 100-10 000 times lower than concentrations of potassium and sodium ions (Uchimura *et al.* 2000). A major difficulty with chemical controls is containing the chemical in the desired area, both to reduce impacts on non-target species and areas, and to maximise the concentration on/around the target pest species. Several techniques have been tested for applying copper ions to control/eradicate *Caulerpa taxifolia* in the Mediterranean. Ion selective membranes that exchange sodium ions inside an enclosed space for copper ions in the surrounding seawater were tested (Gavach *et al.* 1996). The copper ion concentration reaches equilibrium at about 8 ppm inside the membrane and at this level is reported to achieve a 96 % reduction in chlorophyll of the enclosed *C. taxifolia*. However, recovery has been observed after 8 days. Pilot laboratory experiments using copper ions in a supersaturated solution of sodium chloride (to produce an application medium denser than seawater) increased the residence time of the copper ions in contact with *C. taxifolia* in (Charrin *et al.* 1999). Applying copper ions directly to *C. taxifolia* thalli by *in situ* electrolysis resulted in necrotic thalli that were apparently killed (Gavach *et al.* 1999, Rebouillon *et al.* 1999).

Hypochlorite produced *in situ* using an electrolytic cell and applied at concentrations of ~1000 ppm for 10 minutes is reported to have a lethal effect on *C. taxifolia* after 96 h. However, recovery occurred after 8 days – the effect of hypochlorite was merely temporary (Boudouresque *et al.* 1996).

Laboratory tests with a commercial antifoulant (Sea nine 211™) and a red algal extract (Furanone 281), at concentrations of >1.6 mg l^{-1} and 40 mg l^{-1}, respectively, resulted in mortality of *Undaria pinnatifida* gametophytes (Burridge and Gorski 1998). In contrast, much higher concentrations of three commercial terrestrial herbicides (Diuron, Simazine, and Glyphosate) were needed to inhibit zoospore germination of the related kelp *Ecklonia radiata* (Burridge and Gorski 1998, no tests on *Undaria pinnatifida*).

In situ tests have been conducted on *Undaria pinnatifida* with a number of commercial herbicides (Atrazine, Diuron, Casuron, Coptrol and combinations of these chemicals) and lime using different application techniques. These included injection into the stipe or midrib, applying a gel formulation, attaching a sponge saturated with active substance to the thallus, and applying compounds inside a bag enclosing the thalli. All of the methods used proved to be labour-intensive and were ineffective in killing *U. pinnatifida* (Sanderson 1996).

Immersing *Undaria pinnatifida* in freshwater for 24 h resulted in only 90 % mortality of gametophytes in laboratory experiments, whereas air exposure for the same time achieved 100 % mortality (C. Sanderson and S. Blackburn, University of Tasmania/CSIRO; unpublished data).

Saturated salt and 4% hydrated lime solutions were used in an attempt to kill *Codium fragile* ssp. *tomentosoides* fouling oysters in Canada to prevent translocation between areas. The alga was very difficult to eradicate using these treatments although it took a long time to assess their efficacy (MacNair and Smith 1999).

Species-specific chemicals such as pheromones are essential to complete the often multi-stage life cycle in a range of macroalgae (eg. Maier 1993). The main pheromone identified to trigger maturation and fertilisation of the female gametophyte in the family Laminariales (which includes *Undaria pinnatifida*) is lamoxiren. In the Fucales (which includes *Sargassum muticum*) four pheromones have been identified, however no *Sargassum* species were tested (Maier 1993). Lack of species-specificity, potential costly synthesis, short life span in water and difficulties applying compounds in the marine environment complicate the development of this approach.

Partial mortality of algal thalli causes fragmentation and potentially recovery of the targeted area or enhance the spread outside the targeted area.

The main difficulty with chemical treatments is the technical problem of applying chemicals in the marine environment. Any compound is readily diluted and likely to be dispersed over a larger area, depending on local currents. This significantly decreases the concentration and increases contact time required for complete mortality, as well as increasing impacts on non-target species and habitats. In addition to increasing dosage rates, using application media with a density higher than seawater or directly applying compounds (labour intense) have been used to alleviate this problem. Most published trials with chemical compounds did not result in an eradication of the target macroalgae, and recovery occurred frequently.

The non-target effects of chemical treatments are high because all chemicals tested to date lack species-specificity. Of further concern is the accumulation of toxic residues or degradation products in the treated area (in sediments or organisms). Copper residues in the sediment after treatment of *Caulerpa taxifolia* with copper were in the order of 40 mg kg^{-1} (Gavach *et al*. 1999).

5.2.3 Management of spread and translocation

Vector management is an important tool to prevent further spread and translocation of introduced macroalgae. However, very little information is available on the importance of the different potential vectors for macroalgal pests.

The invasive strain of *Caulerpa taxifolia* appears to have originated from the Stuttgart aquarium, from where it was shipped to several public aquaria before accidentally being released into the Mediterranean outside the Monaco aquarium. The spreading of the alga is facilitated by fishing activity, in particular by bottom trawlers and trammel nets. The massive presence of the alga interferes with the use of the gear, reducing fish catches and may also alter fish community composition but also because (Relini *et al* 2000). An undetermined number of strains of *Caulerpa taxifolia* are available for purchase through the commercial marine aquarium trade at shops and over the Internet. There is insufficient information at present to determine which strains of *Caulerpa taxifolia* are invasive and the risks posed by strains not currently thought to be invasive. The Australian Quarantine and Inspection Service (AQIS) banned the importation of Caulerpa taxifolia into Australia under federal legislation in 1997. Sale of *C. taxifolia* as an aquarium plant is now prohibited in New South Wales, under the Fisheries Management Act 1994 since 2000 and it is recommended that all existing aquarium stocks in Australia be destroyed immediately.

Aquaculture operations are likely vectors for *Codium fragile* ssp. *tomentosoides*, a pest economically impacting shellfish fisheries in the United States (reviewed in Trowbridge 1998); the majority of introduced freshwater plants in New England are ‘escapees’ from cultivation (Les and Mohrhoff 1999). Similarly, *Undaria* spread along the French coastline after it escaped cultivation attempts (Floc'h *et al.* 1991). *Undaria pinnatifida* is reported to preferably colonise floating structures (Floc’h *et al*. 1988, 1991; Fletcher and Farrell 1999; B. Forrest, in Sinner *et al*. 2000). For example, treatment of mussel lines, buoys, products, and spat, is essential to prevent the domestic and international translocation of target macroalgal pests. However, the scale of the problem, ie. infection incidence of aquaculture facilities with introduced macroalgae, has not yet been assessed, and treatment options have yet to be developed. Results from trials to treat *C. fragile* ssp. *tomentosoides*-infected oysters with 4 % hydrated lime or saturated salt have been ambiguous (MacNair and Smith 1999). However, a method to sterilise *U. pinnatifida*-infected wharf piles using bromine compounds applied inside PVC sleeves was successfully tested in New Zealand and permits for wider use are being considered (M. O'Callaghan, Department of Conservation, New Zealand, unpublished data).

In France, a tractor drawn harrow was used to clear mussel beds of *S. muticum* with considerable damage to the substratum. A chain dragged between two amphibious vehicles was used to clear shellfish beds but resulted in fragmentation and dispersal of the algae and only 250 of the estimated 1000 tonnes was landed, probably increasing spread of the alga (Ribera and Boudouresque 1995).

Ballast water is a likely vector for macroalgal propagules and fragments; however, the overall importance of this vector is to date unknown. Heat treatment as an application to treat ships' ballast water was found effective in destroying *Undaria pinnatifida* zoospores (Mountfort *et al*. 1999a).

5.2.4 Long-term control and management

Biological control

Tropical ascoglossan molluscs feed on *Caulerpa taxifolia* at a rate of between 0.1 and 0.4 g day^{-1} (ie. up to 2-3 fronds per day), depending on temperature (Meinesz *et al*. 1996). Experiments with two native ascoglossans showed that low densities of the herbivorous slugs led to thallus damage and increased fragmentation (Zuljevic and Antolic 1999c). A complex modelling simulation used to assess the potential of *Elysia subornata* as a biocontrol of *C. taxifolia* found that the greatest impacts are obtained using either some adults or mixing adults and juveniles in a scattered distribution (Coquillard *et al*. 2000).

The rate of ingestion of *Caulerpa taxifolia* by the sea urchin *Paracentrotus* is weak compared to its ingestion rate of other native algae such as *Cystoseira compressa* and *Halopteris scoparia*. However, the echinoid consumes greater quantities of *Caulerpa taxifolia* if it has previously consumed it (Ganteaume *et al.* 1998).

Highly specialised ascoglossan molluscs also feed on *Codium fragile* (Trowbridge 1991, 1993, 1995). It is unclear whether the ascoglossans are native to Australia (C. Trowbridge, Oregon State University, USA; pers. comm.). Grazing by these slugs has been shown to reduce biomass and distribution of *C. fragile*, however, they do not discriminate between the two native and the introduced subspecies (Trowbridge 1999)

Negative effects of sea urchin and abalone grazing on abundance of *Undaria pinnatifida* have been observed in some areas (Floc'h *et al*. 1991, Castric-Frey *et al*. 1993, Agatsuma *et al*. 1997). A decrease in the abundance of *U. pinnatifida* at the French Atlantic coast was observed after grazing by the native gastropod *Gibbula* sp. (ICES 1997). However, they may not eradicate it; Sanderson (1990) reported an *U. pinnatifida* population in an area of high sea-urchin abundance. Experimental studies involving manipulation of sea-urchin numbers in *U. pinnatifida* stands are underway in Tasmania (J. Valentine, University of Tasmania; pers. comm.). The authors are not aware of studies in Australia on grazer preferences between *U. pinnatifida* and co-occurring native macroalgae.

There are a number of reported *Undaria* pathogens: eg. the algal endophyte *Streblonema*; the bacteria *Pseudomonas* spp (7 strains); *Moraxalla* spp (3 strains); Vibrio spp (2 strains); *Flavobacterium* sp.; and several species of copepods and amphipods (Kimura *et al*. 1976; Kitto *et al*. 1976; Campello 1991). However, algal endophytes, parasites and viral, bacterial and fungal pathogens in most cases do not kill the host macroalga, although they may decrease its fitness and competitive ability. Algal endophytes have been reported to infect a number of kelp species, including *Undaria pinnatifida* (Peters and Schaffelke 1996). Information on the systematic position, taxonomic resolution, and host specificity of the endophyte species is still limited (Peters and Burkhardt 1998). It is possible that brown algal endophytes will infect not only *Undaria pinnatifida* but also other native laminarian kelps. A range of pathogenic fungi and bacteria are found in macroalgae (Kimura *et al*. 1976, Kitto *et al*. 1976), however, information on host specificity is sparse.

The authors are not aware of any studies comparing the host-specificity of pathogens infecting macroalgae – a first step in assessing the risks of using pathogens as a long-term control option.

Habitat restoration

Habitat restoration is believed to be a long-term option that decreases invasibility of an area. To date, however, information is scarce on the characteristics that make habitats invasible, as are options to remediate disturbed habitats. Harmelin (1996) reports that artificial reefs have been used in the Mediterranean to increase spatial complexity and promote settlement of native benthos. However, at this stage it is unknown how effective this is in reducing spread and colonisation of *Caulerpa taxifolia*. Other options with the potential to improve resilience of the native benthic community are restoration of disturbed habitat (eg. seagrass beds Campbell 2000) and enhanced recruitment of native species (J. Valentine, University of Tasmania; pers. comm.).

In a number of cases, introduced macroalgae have been found associated with point sources of nutrients, such as outfall pipes for treated sewage or stormwater drains (eg. Campbell & Burridge 1998; Campbell *et al*. 1999a, 1999b). Increased nutrient availability leads to increased growth of some macroalgal species and may lead to a species shift if the original community was adapted to low nutrient availability. Such a shift in species composition can favour the establishment of introduced species. In such cases, management action that reduces nutrient inputs and improves water quality, such as management of upstream sources and legislation to control point sources may improve native community resilience.

5.2.5 Summary

The physical removal of *Caulerpa taxifolia* and (to a lesser extent) *Undaria pinnatifida* has shown some promising results. Successful physical eradication requires early detection, elimination of fragments during the manual removal process, repeated monitoring and continual removals until no regenerating plants are detected. The method is labour-intensive and therefore expensive. Heat-treatment has the potential to be a very useful response option, however, further technical development is needed to resolve difficulties with in-water applications. A number of chemical control options have been tested but had limited efficacy and may lead to increased spread due to fragmentation. Improved application methods are required before chemical options can be considered viable, for example the enclosure and chemical treatment of infected wharf piles or the use of an ion selective membrane to locally increase copper ion concentrations in *Caulerpa taxifolia* beds. Vector management is essential to reduce the spread of invasive macroalgae, but knowledge is limited about the relative importance of different vectors. Biological control using generalist algal grazers is unlikely to control invasive macroalgae, although *Undaria pinnatifida* populations have been reduced in the presence of urchin and abalone grazing. Pathogens, parasites, viruses and endophytes may negatively affect or kill individuals and reduce population size, however, they are often not species-specific and are unlikely to eradicate invasive macroalgae. Habitat restoration is a potential long-term management option that may decrease invasibility of an area and improve the resilience of native benthic communities.

5.3 Ctenophores (*Mnemiopsis leidyi*)

The Atlantic comb jelly *Mnemiopsis leidyi* has dramatically affected the ecology and productivity of the Black Sea since its introduction, probably in ballast water, in the early 1980s. This species has also spread into the Azov, Marmara, and Mediterranean Seas (GESAMP 1997). In the Azov and Black Seas, massive outbreaks of *M. leidyi* have reached standing stocks of hundreds of millions of metric tons - many times the total annual fish catch from all the world's oceans. Major outbreaks of *M. leidyi* occurred during the same period as a 90% reduction in zooplankton biomass and significant decreases in commercial catches of forage fish (anchovy and sprat) in 1989-1991 (Shiganova 1998; GESAMP, 1997). It is not clear if M. *leidyi* was the sole cause of declines in forage fish, because these stocks were under intense fishing pressure in the years preceding their decline (Shiganova 1998). The massive outbreak of *M. leidyi* in 1989 could have been in response to abundant zooplankton made available by the reduction of forage fish caused by overfishing and nutrient pollution. Although the relative causes and effects are unclear, the presence of such a huge biomass of an introduced species represents a substantial change in the ecosystem that could dramatically affect fisheries.

5.3.1 Physical and chemical controls

Presently no effective control methods are known for *Mnemiopsis leidyi*. Physical removal with nets would be ineffective especially as damaged ctenophores heal quickly, although fecundity and feeding rates are reduced (Purcell and Cowan 1995). *M. leidyi* is able to survive in a variety of extreme environmental conditions; it is probably resistant to high levels of agricultural pesticides and anthropogenic pollution. Using available non-specific pesticides to eliminate *M. leidyi* would have far-reaching effects on the ecological community structure in the Black Sea (Harbison and Volovik 1994).

5.3.2 Long-term control and management

Biological control

No viral, bacterial, fungal or protozoan diseases specific to ctenophores have been identified. Several non-specific ciliate protozoans have been observed in the laboratory but it is unlikely that such agents would be efficacious in the field. Parasitic trematode flatworms are found in ctenophores and may reduce their populations. However, as many trematodes also parasitise fish, their introduction as a biological control agent could cause damage to the fisheries in the area (Harbison and Volovik 1994). The larvae of the burrowing anemone, *Edwardsia lineata,* (formerly known as *Fagesia lineata* and *Edwardsia leidyi*) parasitise *M. leidyi* in the northern United States. Bumann and Puls (1996) concluded that *E. lineata* could be a suitable candidate for the biological control of *M. leidyi* populations in the Black Sea. However, the planular larvae of E. *lineata* may also infest native species and the impacts of the adult anemone on the benthic community are unknown. Additionally, the free-swimming larvae are known to cause "seabather's eruption" a dermatitis normally lasting a few days – a disadvantage for the resorts bordering the shores of the Black Sea (Harbison and Volovik 1994).

The Joint Group of Experts on the Scientific Aspects of Marine Environment Protection (GESAMP 1997) concluded that biological control offers the most practical solution to *Mnemiopsis leidyi* in the Black and Azov seas. The three preferred strategies were:

1. Improving the management of fisheries to enhance native fish populations that compete or feed on *M. leidyi* – several indigenous fish species eat ctenophores (Harbison and Volovik 1994);
2. Introducing economically valuable specific predators of *M. leidyi* (eg. the fish *Gadus, Peprilus*, or *Oncorhynchus*). The butterfish *Peprilus triacanthus,* has been reported to control native populations of *M. leidyi* on the North American east coast and was considered a good candidate for introduction (Harbison 1993). More recently a workshop convened by the Marine Conservation Biology Institute, concluded that introducing the suggested specific predators of *M. leidyi* to the Black Sea would be a high risk strategy as they are generalist vertebrate predators (Bax *et al*., 2001). A Mediterranean relative of the *Peprilus triacanthus*, was a preferred biological control agent, because its effects would be restricted to the Black and Azov seas (ie. it would not be an alien species in the neighbouring waters).

3. Introduce a specific comb jelly predator – ctenophores are eaten by a variety of predators including the ctenophore, *Beroe* sp. and the scyphomedusan jellyfish, *Chrysaora quinquecirrha.* Species of the genus *Beroe* are particularly attractive as predators, since all lifestages feed exclusively on gelatinous zooplankton, particularly salps and ctenophores (Harbison and Volovik 1994). *Beroe ovata* has recently been recorded in the Black Sea along the Ukraine coast (introduced from the USA). Visual observations confirm that *B. ovata* forage on *M. leidyi* (Romanova *et al.* 1999) and it may now play a role in decreasing abundance in the Black Sea (Kochina 1999). *C. quinquecirrha* is known to prey on *M. leidyi* and control populations of the ctenophore in the tributaries of Chesapeake Bay, USA (Purcell and Cowan 1995; Kreps *et al.* 1997). However, it is not recommended that *C. quinquecirrha* be introduced into the Black Sea as medusa are capable of inflicting a severe sting to swimmers (Harbison and Volovik 1994).

5.3.3 Summary

Eradication or control of the ctenophore *Mnemiopsis leidyi* provides a major challenge. There seems little likelihood of physical or chemical control. There are some candidates for biological control, but although these fish are claimed to be specific by Harbison and Volovik (1994), they are mostly generalist feeders – the class of biological control agents that have caused most damage in terrestrial environments. Any introduction would be very high risk strategy unless extensive field testing with sterile specimens occurred first. Enhancement of local fish predators is a possibility, although its commercial viability (as a fishery) and impacts on the ecosystem would have to be carefully researched. In addition the potential for a slow growing predator to control a rapidly growing population would have to be assessed.

5.4 Echinoderms (*Asterias amurensis)*

Asterias amurensis arrived in Australia about 20 years ago. Until recently, it was confined to the Derwent estuary, where the population is estimated to be between 3-30 million seastars. Grannum *et al.* (1996) estimated ~30 million seastars in the Derwent River based on a homogenous distribution with depth. A more recent study (Ling 2000) estimated the population in the Port of Hobart to be only ~3 million seastars as he found seastar density decreases with increasing depth. The major threat was if this seastar expanded outside the Derwent estuary, where the risk of damage to the marine environment of southeast Australia, including cultured and wild shellfisheries is extreme. In 1995, several adult *A. amurensis* were found in Port Phillip Bay in scallop dredges. The first evidence of a breeding population was obtained in 1998 when juveniles were collected on a commercial mussel farm. The most recent surveys suggest that the population in 2000 has reached ~120 million individuals (G. Parry, MAFRI; pers. comm.).

5.4.1 Physical control

Physical removal remains the most socially and politically acceptable method to control *Asterias amurensis* and is the only method currently used to reduce seastar numbers in near-shore coastal environments (Martin 1998; Ito 1991). In Rhode Island Waters in 1941 a bounty rate of 75 cents per hundred pounds (45 kg) of native seastars (*Asterias* spp.) was offered to fishermen. In one month a total of 1,211,064 pounds (550 tonnes) of seastars were dredged up and the population was reduced in localised areas (Gibbs 1946). Methods of physical control include manual removal, pole spears, dip netting, seastar “mops”, dredging, trawling, diver collection and trapping. Physical removal is effective only as a tactical control useful in small areas and it is not suitable for large-scale control (Goggin 1998a). It is not effective against the large populations of introduced *A. amurensis* in the Derwent estuary or Port Phillip Bay, but could be useful around marine farms, marine reserves or areas of new incursions.

Manual removal of seastars has been used on aquaculture farms, around oyster racks and grow-up trays, and in the intertidal using dip nets or poles with a long nail on the end to spike the seastars.

Seastar “mops” have been used by the aquaculture industry for many years to reduce seastar predation on oyster stocks in soft sediment areas. In the 1930’s the most commonly used device by the oyster industry on the US Atlantic coast for catching native seastars (*Asterias forbesi*) was a mop consisting of 12-16 large rope yarn brushes, about 1.5m long, attached to a 3m long iron bar, this was towed like a dredge. Seastars were then killed by immersion in troughs of hot water (Lee 1948). Modern mopping consists of towing a frame about 2.5 m wide to which are tied 15 large cotton bundles over the bottom: the starfish get caught on the cotton; the mop is lifted to the surface and the starfish killed in a tub of hot water every 10-15 minutes. An alternative form of seastar mopping practiced on oyster leases in Long Island Sound, Connecticut, uses a rotor cable capable of picking up seastars by its spines. There is little bycatch but this may be due to the lack of benthic diversity in the vicinity of the oyster leases. Mopping ceased in the 1990s as catch rates declined (2-3 seastars per day, 5-6 days a week; Martin 1998), but has been reinstated with a recent upsurgence in population numbers (C. MacKenzie, NEFC, NMFS, US; pers. comm.). In France, oyster farmers use a similar mop device, the “faubert” technique, for collecting native seastars (*A. rubens*) and also a specialised dredge to selectively harvest the seastars. Its efficiency, estimated by diver observation appeared promising (Barthelemy 1991).

In Japan, the HOTAC scallop culture technique relies on plot rotation of areas of the sea floor – these areas are cleared of seastars prior to seeding with juvenile scallops and again during the scallop grow-out period (Ito 1991). Seastars are removed using scallop dredges and traps before reseeding and rope trawls (mops) and trapping after reseeding. While seastars reinvade the cleared areas, a significant number of scallops can be harvested by the end of the three year period (McLoughlin and Bax 1993).

A roller dredge, fished four to a beam has been used to collect *Asterias rubens* in Dutch subtidal oyster beds. The starfish are lifted into suspension with the front roller and then collected in the rear bag. Mops and manual removal are also used (Spencer 1992).

A specialised dredge to selectively harvest the seastars *Asterias rubens* on oyster beds was developed in France. Its efficiency, estimated by diver observation appeared promising (Barthelemy 1991).

There may be secondary impacts of dredging in areas where sediments are highly polluted. Dredging and, to a lesser extent, mopping were not recommended as methods to remove seastars from the Derwent estuary because they could resuspend toxic dinoflagellate cysts and heavy metals trapped in the sediment (Coughanowr 1997), could have a high bycatch of native seastars, could damage the endangered handfish or its habitats and were unlikely to have a significant impact on the population (Goggin 1998a). Dredging is prohibited in Tasmania State waters without approval under the Environmental Management and Pollution Control Act 1994 and the Living Marine Resources Management Act 1995.

In 1993, a year after the positive identification of *Asterias amurensis* in Tasmanian waters but at least six years after the establishment of the seastar, a number of community dives were organised in the Port of Hobart to collect the seastars. More than 6000 seastars (estimated to be ~60% of the population) were collected from an area of 300m x 20m. The next month 3 tonnes (~24 000 individuals) of seastars were collected (Morrice 1995). In May 2000 community divers again collected seastars around the port, the ~15,000 individuals collected around Sullivans Cove were estimated to be 5% of the seastar population in that area (Ling 2000) and in total ~21 000 seastars were collected around the general port area (CRIMP 2000). This highlights the ineffectiveness of diver collection as a control method for large populations.

Habitat management may be able to reduce population size and reproductive success if numbers can be reduced to a level where fertilisation success is reduced. A review on fertilisation success by Levitan and Sewell (1998) found that for echinoderms, manipulating male distance, abundance or density could influence levels of female fertilisation success. Seastars collected around Derwent River yacht clubs and the Hobart docks are present in much greater densities due to the more readily available food sources (primarily fallen mussels from jetty structures as well as hull scrapings and discarded fish scraps and anthropogenically supplied food. Subsequently they are known to have significantly higher gonad indices and hence experience higher fertilisation success (Ling 2000; Morris 2001). Localised physical removal of these populations prior to spawning may reduce recruitment success locally due to lower population densities and increased distances between individuals. Female fertilisation success is known to decrease rapidly with distance in the sea urchin *Strongylocentrotus droebachiensis* (< 10% success if 1 male < 1metre away); fertilisation was negligible at 5 metres even with three males. However, Babcock *et al.* (1994) found a slower decline with distance in fertilisation success in the crown of thorns seastar, *Acanthaster planci* (5% if 1 male 100 metres away). The success of reducing fertilisation success of *Asterias amurensis* by population reduction in the Derwent River and Port Phillip Bay would depend on the rate of decline in fertilisation success with density and the capacity to effectively reduce or remove areas of high density.

After the initial identification of isolated adult *Asterias amurensis* in Port Phillip Bay in 1995, decisions were made to search for and physically remove any further specimens. In 1998, once juveniles had been found and a population had clearly established in Port Phillip Bay, physical removal was considered unfeasible as hand collecting of *A. amurensis* was found to be very labour intensive, costly and ineffective for small cryptic individuals < 50mm (Parry *et al.* 2000).

Trapping trials carried out by the Tasmanian Department of Primary Industries and Fisheries in Hobart found that intensive trapping in areas with low/moderate and high seastar densities failed to control seastars. In fact seastars were found to immigrate rapidly and persistently into the trapped area. Most seastars were caught within the first 24-48 hours and larger individuals dominated catches. Small mesh traps (26mm) caught more seastars than large mesh (65mm) traps. Using traps at the perimeter of an area cleared of seastars by divers was not successful in preventing seastars reinvading the area, even with traps spaced 2.5m apart (Andrews *et al.* 1996). Another problem with trapping is that it only collects individuals large enough to be retained by the trap mesh – if trapping is used for monitoring new incursions, the pest may have been present for sometime before it is actually caught. Infrequent trapping may give juveniles time to mature and reproduce before the next trapping event (Martin and Proctor 2000).

A recent monitoring program around marine farms in Tasmania found that the effectiveness with which traps catch *Asterias amurensis* appears to decline when seastar densities are low or populations are actively moving into or through an area where food is readily available (Martin and Proctor 2000). A similar result was found in Port Phillip Bay when densities were still low (Parry *et al.* 2000). Traps are only likely to be effective in situations where preferred foods are not abundant (eg. where native prey species have been reduced) and the bait is the only easily attainable food source. This may explain why trapping was so successful around the Port of Hobart where high densities of "hungry" seastars are present (Andrews *et al.* 1996), whereas trapping was unsuccessful outside of the Derwent River (Martin and Proctor 2000) despite the presence of seastars in low densities. For seastar infestations which are sporadic over time and have densities less than 2 m^{-2}, diver control is more effective than trapping. However, diver control is not cost effective at depths greater than 12 metres because of diving restrictions (Andrews *et al.* 1996).

Seastars collected in mid -1993 were used for composting trials carried out by the Department of Agricultural Science at the University of Tasmania (Line 1994). Seastars could be made into satisfactory organic mulch suitable for application to agricultural soils. However, commercial exploitation of *Asterias amurensis* seems remote and despite the success of several small scale attempts to produce fertilisers there appears little interest in utilising this source. Seastars are occasionally fished for reduction to animal feed stocks and the curio trade, but reported world seastar fisheries catches are small, unreliable and strongly dominated (up to 98% total catch) by the fishery for *Asterias rubens* in Denmark. The Danish Limfjorf beamtrawl fishery operates from November to April, ice permitting, but only when other more profitable fisheries are unavailable. Seastars are processed and exported to West Germany as an additive to fin-fish meal for poultry feed stocks; 1100 metric tons were harvested in 1982 (Sloan 1985). It is unclear if the fishery still occurs. The harvest of *Asterias* spp. in the USA, for feed stock or fertiliser was examined in the 1940-60's but found to be uneconomical due to high production costs, low product quality, irregularity of supply and low market demand (Sloan 1985 and citations therein).

5.4.2 Chemical control

One of the first attempts to control (native) seastars on commercial shellfish grounds, dating from the turn of the century, used toxic chemicals. Control by chemical agents such as copper and zinc sulphate or chromium salts did not prove practical (Lee 1948 and citations therein), especially around shellfish farms, because of the negative effects on all biota.

Lime, either in slake or hydrated form, is highly alkaline and corrodes the carbonate skeleton of seastars. Quicklime (CaO_2) deployed in porous bags has been used as a barrier control around commercial shellfish farms since the turn of the century and is still used in Korea to control *Asterias amurensis*, and in Canada and the US against *Asterias vulgaris* and *Asterias forbesi* (Thresher *et al.* 1998; C. MacKenzie, NEFC, NMFS, US; pers. comm.). Trials of the broadcast application of quicklime have found the key to success is the dispersal of a relatively uniform layer of the lime over extensive areas. Seastars are exposed to the corrosive particles as they settle or crawl over it. The seastars stop feeding very shortly after the lime touches them, lesions form after 24-48 hours and seastars usually die within two weeks. The lime can dissolve in about 48 hours leaving no residue (C. MacKenzie, NEFC, NMFS, US; pers. comm.). However, in field trials, lime remained effective for several weeks after deposition, but at a much reduced kill rate. Loosanoff and Engle (1942) found that lime dispersed by shovelling or hosing it into the water resulted in an non-uniform dispersal pattern but at 200 pounds per acre (221 kg per hectare) resulted in mortalities up to 70%. In contrast to its reported successful use by commercial oyster farmers, C.L. Goggin, CRIMP; unpublished data in Thresher *et al.* (1998), reports that seastars must be in contact with the lime for lengthy periods (>5 hours) in order for it to be effective, and in a relatively two dimensional habitat where they are unable to evade the lime.

The use of chemicals to control the seastar is unlikely to be acceptable to the Australian public. There is little public support for the broadcast application of quicklime to kill seastars despite the ease in obtaining suitable quantities due to its industrial uses and relatively cheap costs. The adverse effects to the environment (likely to affect sediment processes because of large scale pH changes) and human health present a deterrent to the use of quicklime (although these have not been fully explored). While quicklime has only slight effects on molluscs (Loosanoff and Engle 1942) it has severe effects on crabs.

Chemicals could be used to kill juvenile seastars on commercial mussel ropes so that the seastars are not translocated beyond their current distribution, although freshwater may also be effective and would be less expensive and toxic to the environment (Goggin 1998a). Current research at MAFRI, Victoria is underway to find an appropriate treatment for mussel ropes transferred between Port Phillip Bay and Westernport Bay (L. Gunthrope, MAFRI, pers. comm.)

Injection of poisons (formalin, copper sulphate, hydrochloric acid and ammonia) using pole spears was found to be locally effective for the control of *Acanthaster planci* on the Great Barrier Reef. Kill rates were close to 100% depending on the poison used with copper sulphate recommended as the safest and easiest to use (Birkeland and Lucas 1990). This method is not considered useful for *Asterias amurensis* as it does not have the toxic spines of *A. planci* and so can be collected rather than poisoned and left to die. Given the vast numbers of *Asterias amurensis* present this method would be too time consuming and not viable given the maximum rate of 140 injections per hour. Physical collection methods are likely to be more successful and there is always the problem of thousands of toxic rotting seastars on the benthos and the subsequent environmental impacts of the chemicals to the sediments and associated species (Thresher *et al.* 1998).

5.4.3 Management of spread and translocation

Public education

Seastars have not spread from the Derwent to Tasmania's East coast to the degree expected. While the estuarine circulation (Morris 2001) aids retention of seastar larvae within the Derwent River, it is still a leaky system, with seastars slowly spreading along the coasts outside the estuary. Reducing population abundance in the Derwent could reduce the risk of the population "naturally" spreading beyond its current range. Seastars around the Port of Hobart are known to aggregate on anthropogenically supplied food (eg. mussels scraped from boat hulls or marine farms, fish scraps from commercial or recreational vessels) and also natural mussel fall from wharf piles. Densities in these areas are extremely high (see Morrice, 1995; Grannum *et al.* 1996). Education of the public to reduce these inputs may cause the seastars to disperse reducing fertilisation success (Goggin 1998a). Seastars found in Derwent River yacht clubs have high gonad indices and could act as a source of larvae for to other areas (Morris 2001). Localised removal of these populations and decreasing their extraneous food sources may reduce fertilisation success, as well as decreasing risks of translocation of seastars around the State by recreational vessels moored in these areas. Food sources could be reduced by changing: hull and mooring cleaning protocols (on shore v. in water); slipway management protocols (to prevent hull scrapings going back into the water); and discouraging the cleaning of fish at boat ramps where innards are thrown into the water. The benefits of public awareness are evident in the early reports in Port Phillip Bay where the first three sightings of adult *Asterias amurensis* were all reported by scallop fishers and the first juveniles were reported by mussel growers. This enabled the authorities to undertake surveys in these areas to determine the extent of the invasions and track them over time (Parry *et al.* 2000).

Marine farm management

Detecting pest species at an early stage of an incursion on marine farms may permit the farmer to minimise the impacts of the pest on farm production, limit its spread within a lease, or prevent it from being spread to other areas (Martin and Proctor 2000). Suspended mussel lines and scallop spat collecting bags have been known to collect *A. amurensis* and *A. rubens* as settled post-larvae in Japan, Tasmania and Ireland (Spencer 1992; Morrice 1995). There is an awareness in Tasmanian and Victorian aquaculture industries of the need for marine farm management and control of stock movement to restrict the further spread of seastars (Garnham 1998; Whayman 1998). Transferring larval/juvenile seastars settled on aquaculture structures (mussel ropes and oyster seed trays) between farm sites (eg. from spat collection areas to grow-out areas), often over distances of 10-100's of kilometres (ie. Huon River to Norfolk Bay in Tasmania, or Port Phillip Bay to Westernport) is a major issue for the industry. Preliminary examination of methods including the effectiveness of quicklime, freshwater and air exposure to kill seastars are discussed below. These methods, in conjunction with management strategies and public education to restrict translocation of seastars by other methods (eg. fishing and recreational vessels) could restrict the rate of spread of the seastar (Goggin 1998a).

Freshwater immersion has been found to be a successful method of killing *Asterias* larvae, with larvae unable to survive exposures to salinities less than 9.75 ppt, and extensive cellular damage occurring after 1-2 minutes (Sutton and Bruce 1996). Marsh (1993) found that adult *A. amurensis* could survive immersion in 26 ppt but at 24 ppt seastars were dead in nine days. However, research underway at MAFRI, Victoria has found that freshwater treatment can cause juvenile mussels to drop off mussel ropes. Instead, placing the mussel ropes in containers with elevated carbon dioxide levels appears to be successful in killing the epibiota without harming the mussels (L. Gunthrope, MAFRI, pers. comm.)

Recent work by mussel growers in Port Phillip Bay indicated that 24 hour air exposure kills small (50-70mm arm length) individuals of the native seastar *Coscinasterias muricata* and many epiphytic biota on mussel ropes. However there is always likely to be some survival of individuals in amongst denser clusters of mussels (Garnham 1998).

5.4.4 Long-term control and management

Biological control

Biological control measures against *Asterias amurensis* include classic biological control, the use of natural chemicals and genetic or molecular manipulation of seastar physiology. One of the few options for the biological control of *A. amurensis* is the ciliate *Orchitophrya stellarum* found in Japanese specimens, a parasitic castrator of the seastar (Goggin and Bouland 1997). *O. stellarum* has not been found in Australia and little is known about the life history or host specificity of this ciliate or its effect on native seastars. Further research on the safety and efficacy of *O. stellarum* as a biological control agent in Australian waters is required (Goggin 1999). Other possible biological control agents for *Asterias amurensis* are sporozoans, dendrogastrids (Ascothoracida: Crustacea), eulimid gastropods (Goggin 1998b).

A number of control options involving manipulating chemicals that control specific life history events substances have been reviewed by N. Murphy, CRIMP; unpublished report, and by Thresher *et al.* (1998). Possible options include saponins, toxins, spawning inhibitors, spawning inducers, sexual pheromones, mucus barriers, and antiviral substances. These compounds would first have to be isolated, tested and then a biological method for mass production devised (eg. synthesis by bacteria or non-native molluscs)

Genetic methods that block meiosis or reduce fitness may provide a control technique that could eradicate *A. amurensis* in the long term. Three broadly different approaches have been suggested that could be applied to the seastar. These are inducible fatality genes (transgenic technology), repressible sterility (gene/chromosome manipulation) and prey or parasite-vectored reproductive inhibition (Thresher and Grewe 1998).

5.4.4 Summary

Physical control of *A. amurensis* is possible but realistically restricted to isolated areas such as marine farms in shallow areas. There is considerable worldwide experience in physical control techniques for seastars using eg. mops, although impacts on native seastars would have to be considered if these techniques were used over wider areas. Quicklime is a chemical method with local application. Broader control of the seastar requires some biologically vectored agent (predator, parasite, or genetic construct) to be cost-effective. Management of population densities and reducing anthropogenic food sources may be able to reduce reproductive success if numbers can be reduced to a level where fertilisation success is reduced.

5.5 Molluscs (*Corbula gibba, Crassostrea gigas, Musculista senhousia, Potamocorbula amurensis* and *Mytilopsis sallei*)

The Mytilacea (*Mytilus edulis*, *Musculista senhousia*, *Perna* spp, *Limnoperna fortunei*) and the Dreissenacea (*Dreissena polymorpha*, *Dreissena bugensis*, *Mytilopsis sallei*) are perhaps the most specialised and most successful Heteromyarian bivalves. Both groups can cause considerable problems as fouling organisms. Mytilids are found in the intertidal and subtidal marine and estuarine environment as well as freshwater. Dreissenids are restricted to estuaries and freshwater and are less desiccation resistant than most of the mytilids (Morton 1974). Available evidence suggests that the ancestors of the modern Corbiculoidea gave rise to forms that ultimately produced the various species of *Mytilopsis* and *Dreissena* (Sprung 1993). The corbiculids *Corbicula fluminea* and *Corbicula flumineus* cause problems in freshwater conduits and *C. fluminea* is used as a bioindicator species in Argentina (Boltovskoy *et al*. 1997).

The following of the above mentioned species are introduced into Australian waters *Corbula gibba*, *Crassostrea gigas*, *Musculista senhousia* and *Mytilus edulis*. Occasional specimens of *Perna viridis*, *P. canaliculus* and *Mytilopsis sallei* have been recorded in Australia.

The Corbuloidea (*Corbula gibba*, *Potamocorbula amurensis*) have a shell, with conchiolin layers, that retards shell dissolution in waters undersaturated in calcium carbonate and increases mechanical shell strength. Increased shell strength decreases predation by crustaceans and fish and inhibits drilling by predatory gastropods (Kardon 1998). Corbulids are used as bioindicator species in Europe (*C. gibba*) and Asia and USA (*P. amurensis*). Both the Corbuloidea and Corbiculoidea are known to bioaccumulate heavy metals to high levels (Pereira *et al*. 1992; Brown and Luoma 1995; Pereira *et al*. 1999). *Corbula gibba* is able to withstand almost anoxic conditions (0.18-0.37 mg oxygen l-1; Christensen 1970) and highly polluted areas (Zarkanellas 1979; Pearson and Rosenberg 1979; Rygg 1985; Crema *et al*. 1991; Adami *et al*. 1997). This may be due to its unique shell structure (thick, tight fitting unequal shell valves), its habit of parting shell valves only slightly when feeding and its ability to remain closed for long periods (Morton 1996). *Potamocorbula amurensis* is a comparatively thin, fragile shell more subject to breakage than *C. gibba* (Carlton 1999b).

The Pacific oyster *Crassostrea gigas* was introduced into the seed production area of Port Stephens in New South Wales sometime prior to 1985. In 1985 the New South Wales Agriculture and Fisheries Department declared the Pacific oyster a noxious fish, making culture and presence of the oyster on a shellfish lease illegal. After several years of trying to eradicate the Pacific oyster, because it outgrows the (preferred) native rock oyster *Saccostrea commercialis*, the government ended eradication attempts and allowed the cultivation of *C. gigas* (Holliday and Nell 1987; Lipton *et al*. 1992).

Carlton (1992) predicted the establishment of the New Zealand green mussel *Perna canaliculus* in California where it is imported live daily in large numbers for direct human consumption. P. canaliculus is unlikely to establish in Australian waters from legal seafood imports as AQIS are required to certify that the mussels are dead (ie. they are only imported cooked in the half shell or frozen). The likely source of introduction of green mussels to Australia continues to be from shipping – the Asian green mussel (*P. viridis*) has been detected and removed from recreational vessels entering Darwin marinas (A. Marshall, DPIF, NT; pers comm.).

5.5.1 Physical control

Methods for physical control of biofouling bivalves include manual or mechanical collection, filters and sieves in water piping, temperature treatment (thermal shock, high heat or freezing), salinity manipulation, desiccation, oxygen deprivation, electric current or cathodic protection, ultraviolet light treatment and water flow velocities. The application of these treatments depends on the habitat of the pest species and the likely impact to the surrounding environment. Fouling mussel species have been removed by scraping by divers, mechanical cleaning (known as pigging), carbon dioxide pellet blasting (akin to sand blasting), and high pressure water jets (Morton 1977; Boelman *et al.* 1997).

Perna canaliculus was successfully eradicated from the shipping channel adjacent to the Outer Harbour wharf in the Gulf St Vincent in South Australia in 1996. A mature population of 12-24 mussels, all of a similar size attached to a razor fish was manually collected during a research SCUBA dive. Subsequent dredging and diving on areas likely to be colonised by the mussel found no more mussels (PIRSA 1999).

In many locations in New Zealand the harvesting of wild *Perna canaliculus* mussels by handpicking, snorkelling and grabs for domestic use and commercial markets has greatly diminished wild populations (Paul 1966; Jeffs *et al.* 1999). Commercial dredge fisheries for subtidal *Perna canaliculus* between 1927-1966 and 1962-1967 were closed to protect over-exploited populations of the mussel in the Hauraki Gulf, Tasman Bay and Kenepuru Sound. Developing a recreational or commercial fishery for populations of fouling mussels could play a part in controlling mussels if introduced into Australia. However, since *P. canaliculus* is a favoured seafood species, problems may occur with individuals trying to establish populations elsewhere. In addition, New Zealand experience shows that intensive dredging of *P. canaliculus* beds on sand or mud removes juveniles and shell matter leaving an unstable soft substrate no longer suitable for settlement and attachment of many sessile invertebrates (Stead 1971a, 1971b cited in Jeffs *et al.* 1999). Environmental impacts of this type of control (eg. for *Perna* and *Musculista* on soft sediment) would be high.

Dredging or beam trawling to collect *Musculista senhousia* may be a possible control technique as the mussels form large colonies in intertidal mud flats in estuaries and sheltered bays. The animal lies buried vertically in the mud, anchored in position by a well-developed byssus (Morton 1974). If biotic or abiotic disturbances cause a mat to break into small pieces, resulting fragments would be most likely swept away rather than form new mats elsewhere (Creese *et al.* 1997). Because *M. senhousia* is also found as a fouling organism on pylons and panels where they do not build byssal nests (Willan 1987), dredging may be only one component of a successful eradication effort.

Corbula has a thick shell and is generally resistant to trawl damage (Morton 1996). In areas of high density, dredging would be unlikely to remove all the individuals. *Corbula gibba* can occur in densities up to 53, 000/m^2 in its native regions (Jensen 1990). Scientific dredging in Port Phillip Bay in 1995/6 collected hundreds of thousands of specimens of *C. gibba* in a short space of time, almost to the exclusion of other species (Hewitt *et al.* 1999).

Potamocorbula laevis and *Corbicula fluminea* are commercially harvested for poultry feed, for shrimp feed and for fertiliser in China and Taiwan (Morton 1977; Carlton *et al.* 1990 and citations therein). However the possibility of harvesting these species in their introduced range for a food source or fertiliser is unlikely to be economically viable or publicly acceptable given the impacts on native species caused by dredging.

In freshwater environments, filters are used to stop movement of pest species such as *Dreissena polymorpha* through pipe work in hydroelectric facilities (Claudi and Mackie 1994). In the marine environment, filters have been used to control settlement and clogging of pipe work by *Perna viridis* in Indian power stations (Rajagopal *et al.* 1996).

Thermal shock (flushing with hot water) is used in some regions of the US to control fouling species in hydroelectric stations (Claudi and Mackie 1994). Water temperatures in excess of 40°C have been shown to kill *D. polymorpha* (Morton 1977; Boelman *et al.* 1997). Usually twice a year, heated water is pumped through water-intakes to kill newly recruited zebra mussels. Some industrial plants also permanently heat flow-through water to temperatures greater than the thermal tolerance of the species (eg. Murray Station, Barrett-O'Leary 1995). A combination of heat and chemical oxidants (chlorine or ozone) allows lower temperatures (30°C) to be used and reduces heating costs (Harrington *et al.* 1997).

Temperature has been found to affect reproductive success in *Musculista senhousia* and *Xenostrobus securis* (as *Limnoperna fortunei kikuchi*) in Japan. A study found that larvae kept at 15°C failed to develop to the pediveliger and settle, explaining why larval settlement did not occur in winter although the species were reproductive all year round (Kimura and Sekiguchi 1996; Morton 1996).

In the Netherlands, the subtropical Asian clam, *Corbicula fluminea* is normally restricted to thermal plumes from power and chemical plants. In winter, populations experience high mortality due to low temperatures (Graney *et al.* 1980). When temperatures rise, clam populations can grow rapidly and these plume areas serve as reproductive sources for range extension during summer. The inability of this species to tolerate low temperature and the lack of suitable habitat in industrial areas suggest that *Corbicula* is not likely to be a serious problem in the Netherlands (Jenner and Janssen-Mommen 1993).

Emersion and dewatering, causing exposure to freezing or high temperature conditions, may be control options for mussels in confined areas. In some power plants, raw water systems, reservoirs, locked marinas and impoundments, water levels can be lowered to expose mussel infestations to the air. Subsequent freezing or desiccation depending on ambient temperatures may kill a large proportion of the exposed population (Boelman *et al.* 1997). The dreissenid mussels (*Dreissena spp.)* and the mytilid mussels *Musculista and Limnoperna* have thin shells and are quick to desiccate when exposed to the air. These species are generally absent from sites that are likely to dry out at low tide (Morton 1974; Willan 1987). Heat treatment may be an effective method for controlling mussel fouling in power plants, provided that such treatment is compatible with plant design (Ricciardi 1998), but would prove difficult to implement in open marine conditions unless fouled habitats can be isolated eg. wharf pylons.

Heat treatment is likely to be ineffective for thick-walled organisms such as oysters; exposure to 70°C water for 40 seconds did not raise the core temperature of the oysters above 24 °C but killed associated boring spionid polychaetes (Nel *et al.* 1999).

Potamocorbula amurensis, *Corbula gibba* and *Corbicula fluminea* have salinity tolerances of < 1-33 ppt (Carlton *et al.* 1990), 28-34 ppt (Jensen 1988) and 0-3 ppt (Gunther *et al.* 1999) respectively. While prolonged emersion in freshwater or saltwater baths may be effective in controlling *Corbula gibba* and *Corbicula fluminea* respectively, their typical occurrence in open water habitat precludes this as a control option. *Crassostrea gigas* has a salinity tolerance of 2-35 ppt; freshwater immersion is used to control the oyster drilling gastropod *Ceratostoma inornatum* without harming the oysters (Mueller and Hoffman 1999). *Mytilopsis sallei* can tolerate salinities ranging from freshwater to 50ppt (Karande and Menon 1975; Raju *et al.* 1975).

Electric current, cathodic protection, ultrasonic vibrations and electromagnetic fields have been trialed to remove fouling mussel species (Morton 1977; Lewis and Pawson 1993; Claudi and Mackie 1994). Until recently, electroshock was not considered feasible because of safety issues, the voltage required, the length of exposure, and the amount of power required (Claudi and Mackie 1994). However an experimental 20kV pulse has been shown to suppress zebra mussel settlement by more than 80% in a Mississippi power plant water cooling system. The pulsed power method stuns or kills veliger larvae in the pipe entrance but has no effect on animals upstream of the entrance or downstream from the system discharge (Marshall 1999). This method has also been used since the 1960's in the USSR (Morton 1977 and citations therein).

All wavelengths of UV-B radiation are effective in killing both veliger and post-veliger larvae of *Dreissena polymorpha* and preventing their settlement. Adult mussels were more resistant but could be killed with longer exposure. The use of UV radiation was considered preferable to chemical control because it was neither polluting nor labour intensive. Ongoing research is aimed at the development and installation of an UV treatment unit for water conduits (Chalker-Scott and Scott 1998).

Flow velocities of more than 1.2m/second reduce settlement of *Perna viridis* larvae, but once established, the mussels can withstand velocities (water shear) ranging from 1.5-2.5m/second (Rajagopal *et al.* 1996). Flow velocities exceeding 2m/second detach D. *polymorpha* (Morton 1977).

In attempts to remove fouling from cultured oysters in Alabama, USA, oysters have been treated with high pressure water jets, heat, exposure to sun, freshwater or saturated salt dips, hydrated lime solution dips, insecticides, herbicides and biological control using native crab species and algal grazing gastropods (Rikard and Wallace 1997; Cigarria *et al.* 1998). Of these methods only the lime solution and crab predation caused significant mortalities to the oysters.

5.5.2 Chemical control

The ability of bivalves to close their shells in the presence of potential toxic chemicals reduces the effectiveness of many chemical treatments, unless concentrations are maintained at a high level for an extended period. Treatment is much easier in enclosed areas such as pipes, than in open areas where they coexist with a natural community. Chemicals are commonly used to control *D. polymorpha* in the USA and Europe.

Chlorine is currently the most common chemical used to control bivalve fouling. Other chemicals including copper sulphate, potassium, synthetic and organic molluscicides in addition to polyquaternary ammonium and benzothiazole compounds, antifoulants (containing TBT, copper oxides or zinc salts or silicon coatings) have been tested and used to a lesser extent. The main disadvantages of chlorine are its lack of specificity, the difficulty in maintaining high concentrations in warm shallow water bodies, and the impact of trihalomethanes. Also increasing environmental concern about the discharge of chlorinated water to the environment has resulted in the introduction of stricter legislation on effluent discharge in the USA and the Netherlands that may make continued use of chlorine difficult (Claudi and Mackie 1994; Rajagopal *et al.* 1997a).

Continuous chlorination using chlorine gas or hypochlorite is commonly used in cooling conduits of seawater cooled power stations to prevent settlement of fouling organisms, particularly mussels (*Mytilus edulis* or *Perna viridis*). Intermittent chlorination is generally ineffective in preventing mussel settlement and growth as mussels that settle between the chlorine pulses were able to resist subsequent exposures to chlorine. Studies have found that mussels treated with chlorine residual concentrations of 4.43 mg l^{-1} for 49 hours were capable of making a recovery but failed to recover after a 24 hour exposure to a chlorine residual concentration of 8-40 mg l^{-1} (Lewis 1985 as cited in Rajagopal *et al.* 1996). Continuous chlorination at a residual chlorine level of 0.1-0.25 mg l^{-1} had no effect on settlement of *M. edulis* in the Netherlands (Jenner 1983), while Rajagopal *et al.* (1996) found that chlorine levels between 0.2-0.5 mg l^{-1} prevented settlement for 30% of *P. viridis* larvae.

Chlorination is also used to control settled *D. polymorpha*, *Corbicula fluminalis, C. fluminea* and *Limnoperna fortunei* in freshwater reservoirs, treatment works, power stations, waterways and raw water supply systems and *Brachidontes* (*Modiolus*) *striatulus* in (estuarine) Indian waterworks (Morton *et al.* 1976; Rajagopal *et al.* 1997b). The chlorine is usually injected as a gas at 1ppm or as chlorine dioxide, with water temperature affecting efficacy. According to Jenner and Janssen-Mommen (1993) and citations therein, *C. fluminea* could be killed by continuous chlorination in 2-3 weeks at total residual chlorine concentrations of 0.5 mg l^{-1} and water temperatures of 20-25°C. At other locations, differences in physical parameters will cause variation in chlorine concentrations needed for effective control. Mortality of larval *D. polymorpha* and *M. edulis* occurs at residual chlorine concentrations as low as 0.1 mg l^{-1} while adults require at least 1 mg l^{-1} depending on exposure time and water temperature (Van Benschoten *et al.* 1993; Rajagopal *et al.* 1997a). A continuous residual chlorine concentration of 1.5-2.0 ppt for 60 hours killed and removed adult *Mytilopsis sallei (*Karande *et al.* 1982). *Mytilopsis leucophaeta* is more tolerant to chlorine than *M. edulis* and *D. polymorpha* (Rajagopal *et al.* 1997a).

Continuous chlorination forces closure of the shell valves of bivalves cutting off the supply of oxygen and food enriched waters and preventing the expulsion of carbon dioxide and other waste products (Morton *et al.* 1976). Continuous chlorination at a low concentration of 0.5 mg l^{-1} has been used to control *Limnoperna fortunei* fouling in freshwater supplies in Hong Kong. Dense fouling may require an initial high dose of chlorine (eg. 200 mg l^{-1}) and then the application of a low dose 1.0 mg l^{-1} for several days to weeks, dependent on the fouling species. Repetition at 2-3 month intervals is usually effective in keeping conduits clear. If chemicals are applied after and during spawning periods, settlement and recolonisation of the system by newly metamorphosed mussels is prevented (Ricciardi

1998). A selective summary of the details of chlorination of various mussel species in power plant biofouling control is given in Rajagopal *et al.* (1997b).

Electrolysis of seawater to produce chlorine has been successfully used to control fouling on seawater inlets of ships and shore structures under laboratory and field conditions (Ganti and Kalyanasundarum 1975).

Chlorination has long been used in the aquaculture industry to disinfect oysters and other shellfish from potentially contaminated, bacterially infected waters. Ultraviolet radiation is more frequently used in shellfish depuration facilities these days (Scott *et al.* 1982). Chlorination was also trialed (unsuccessfully) on imported shellfish to kill associated biofouling organisms and on effluent waters from quarantine holding tanks (eg. MAFF Fisheries Laboratories, UK; Utting and Spencer 1992; Australian Quarantine and Inspection Service; Doyle *et al.* 1996).

Copper sulphate is an effective biocide routinely used in aquaculture and to kill snails that host schistosomiasis to protect human health. The main disadvantages of copper use are that it is absorbed by soil and organic material, is ineffective at high pH and is toxic to many non-target organisms. Copper in particular is very toxic for *Corbicula fluminea*, especially juveniles (Graney *et al.* 1983; Harrison 1984; see Doherty and Cherry 1988 and Doherty 1990 for detailed tolerances to many pollutants including halogens, heavy metals and organic compounds). Longer-term exposure of the clams to copper at 0.008 - 0.017 mg Cu l^{-1} resulted in impairment of growth resulting in dwarf populations (Belanger *et al.* 1990). *Mytilopsis sallei* is more resistant to copper than oysters (*Crassostrea gigas* and *C. virginica*) and mussels (*M. edulis*) with LC_{50} values of 0.6 mg l^{-1} for 4 days, 1.9 mg l^{-1} for 4 days, 0.103 mg l^{-1} for 2 days (embryos) and 0.14–1.0 mg l^{-1} for 2-7 days respectively (Rao and Balaji 1994). The relative toxicity of heavy metals to *Mytilopsis sallei* based on 96 hour LC_{50} values is copper (0.6 mg l^{-1}), cadmium (0.71 mg l^{-1}) and zinc (8.63 mg l^{-1})(Devi 1995). None of the commercially available antifouling paints or wood preservatives containing copper used in India on vessels prevents heavy fouling of *Mytilopsis sallei*, even for a period of 6 months. Chlorinated rubber-based paints containing TBTs offered some resistance for nearly a year (Rao and Balaji 1994).

Mytilopsis sp. was eradicated in three locked marinas in Darwin harbour, Australia, using chlorine and copper sulphate. This control attempt was successful because the mussels were in small enclosed water bodies separated from the surrounding ocean (Bax 1999). High ambient temperatures in Darwin meant that it was difficult to maintain residual chlorine concentrations high enough (> 2ppm) to guarantee a complete kill in a reasonable time (especially in laboratory trials). Copper sulphate was used instead of, or in addition to, the chlorine to ensure the complete kill of mussels.

Some examples of other chemicals used to control *Dreissena polymorpha* are listed in Table 2. In non-potable waters, a variety of molluscicides can be used whereas in potable water sources, chlorination or heat treatment is preferred because of potential impacts on human health. Sodium pentachlorophenate (NaPCP) is no longer used as a molluscicide because of potential harmful effects on handlers and the environment. Niclosamide (Bayluscide) by Bayer has been and continues to be the chemical of choice against snails for human schistosomiasis control since the 1960's; it can cost \$100/kg but 100% adult mortality can be obtained at concentrations as low as ~1 mg/l after 2-h exposure. Its main drawbacks are its price and impacts on certain algae, aquatic plants and fish (Perrett and Whitfield 1996).

Other molluscicides used to control *Dreissena polymorpha* and *Corbicula fluminea* are TCMTB (2-thiocyanomethylthio-benzothiazole) an aromatic hydrocarbon and PQ1 (poly-oxyethylene-dimethyliminio-ethylene-dimethyliminio-ethylene dichloride) a cationic polyquaternary ammonium compound. As TCMTB >1 mg kg^{-1} or PQ1 >2 mg kg^{-1} can induce 100% mortality in zebra mussels and Asian clams more rapidly than exposure to 0.3-0.5 mg kg^{-1} residual chlorine (336-505 hours), they may be more effective molluscicides for the control of bivalve macrofouling in raw water systems (McMahon *et al.* 1993). Exposure of *D. polymorpha* and *C. fluminea* to the cationic surfactant-based molluscicide DGH/QUAT resulted in a similar degree of mortality after 24 hours although *D. polymorpha* experienced significantly higher mortality rates in shorter time periods (6 hours) than *C. fluminea* (Bidwell *et al.* 1995). The organic molluscicide Mexel-432$^{®}$ is a new antifouling product designed to remove invertebrate fouling in water cooling systems. This compound is very effective against zebra mussels and can be used as an alternative to chlorination. In vitro experiments using tissue from *Crassostrea gigas* has shown reduced metabolic activity and cellular damage (Domart-Coulon *et al.* 2000).

Table 2. Chemicals used to control the zebra mussel, *Dreissena polymorpha*, in the United States.

Chemical treatment	Citation
Chlorine • Sodium hypochlorite - NAOCl, • Chloramines - NH_2Cl, $NHCl_2$, NCl_3, • Chlorine dioxide - ClO_2, • Sodium chlorite - $NaClO_2$	Claudi and Mackie, 1994; Boelman *et al.* 1997; Harrington *et al.* 1997
Bromine • activated bromine • sodium bromide • bromine chloride • ACTI-Brom by Nalco Chemical Co. • Bromicide by Great Lakes Chemical Corporation	Claudi and Mackie, 1994; Boelman *et al.* 1997;
Non-oxidising molluscicides based on polyquaternary ammonium compounds • Clamtrol – CT2- Betz Chemicals • Calgon H-130- Calgon Corporation • Macrotrol 7326 – Nalco • Mexel 432- RTK Technologies • Bayer 73- Mobay Corporation • Sal I (Salicylanilide I) – Aldrich Chemical Co. • TFM – Hoescht	Barrett-O'Leary 1994; Claudi and Mackie, 1994; Command and Matthews 1994; Fisher *et al.* 1994; Boelman *et al.* 1997
Flocculation chemicals • Aluminium sulphate	Boelman *et al.* 1997
Ozone injection	Barrett-O'Leary 1995a; Boelman *et al.* 1997; Harrington *et al.* 1997
Potassium permanganate	Barrett-O'Leary 1994a; Balog *et al.* 1995; Boelman *et al.* 1997
Cationic polymer • Calgon Catfloc LS)	Blanck *et al.* 1996
Polycyclic aromatic hydrocarbons • acridine	Kraak *et al.* 1997
High molecular weight polymer • Dimethyl-Diallyl-ammonium chloride	Blanck *et al.* 1996
Controlled electrolytic dissolution of copper and aluminium anodes	Blume and Fitzgerald 1996
Natural plant extracts • eg. Endod from the soap berry plant	Wright and Magee 1997; Lemma *et al.* 1991
Antioxidising chemicals	Cope *et al.* 1997

Endod which has been used to control zebra and quagga mussel infestations, contains the molluscicidal saponin lemmatoxin (extracted from the soap berry bush *Phtyolacca dodecandra*) (Lemma *et al.* 1991; Wright and Magee 1997). Much attention has been given to the development of molluscicides from plants in the hope that they might provide cheap, biodegradable and effective control agents against the snail responsible for the spread of human schistosomiasis. Recent results indicate that the use of such molluscicides will be limited to areas where the plants grow naturally in abundance (Perrett and Whitfield 1996).

The effects of 52 pesticides, herbicides and other compounds on oyster and clam embryos and larvae were described by Davis and Hidu (1969). These included DDT, Dieldrin, Endrin, Lindane, Sevin (carbaryl), 2,4-D, Diuron, Fenuron, pentachlorophenol and phenol. Most of the compounds affected embryonic development and some had drastic effects on larval growth and survival. They concluded, differences in toxicity to bivalve larvae among the compounds of each category of pesticide are large enough that it should be able to select compounds to control (non-bivalve) pest species without serious damage to commercial shellfish. The cyclodiene pesticide Endosulphan inhibited heart rate and caused respiratory toxicity in *Mytilopsis sallei*, however concentrations that caused mortality were not presented (Rao *et al.* 1988).

5.5.3 Management of spread and translocation

Corbulid species can survive long periods in ballast water and can generate heavy or at least significant populations in foreign harbours (eg. *Potamocorbula amurensis* in San Francisco Bay, USA; Carlton *et al.* 1990). For these reasons, Healy and Lamprell (1996) recommended that the population of *Corbula gibba* in Port Phillip Bay should be monitored and that vessels operating out of the bay should not take on ballast water.

Mytilopsis sp. is thought to have spread to Darwin marinas on the hulls of recreational yachts. Since the eradication in 1999, further specimens have been observed on international yachts arriving in Darwin (A. Marshall, DPIF, NT; pers. comm.). Due to the ability of the mussels to stow away inside hollows and tubes not readily visible underwater, haul out of the vessels for inspection on land is the preferred approach to reduce the risk of re-invasion.

An aquatic nuisance species dispersal barrier is being developed for the Chicago Sanitary and Ship Canal, a man-made canal between the Mississippi River and Great Lakes drainages. Due to the commercial uses of the canal and its importance to Chicago’s drinking water, closure of the canal or installation of physical barriers were not considered practical and chemical control was recommended for use only as an emergency measure. The project has three phases. Phase 1 will target bottom dwelling species, phase 2 will target actively swimming organisms in the entire water column and phase 3 will address planktonic organisms. Phase 1 will consist of an electric barrier array while phase 2 is the implementation of the full water column electric barrier, dependent upon safety and liability concerns. Other methodologies under consideration or development include infrasound, bubble screens and water jets (Moy 1999).

Aquaculture facilities routinely use settlement ropes to collect spat to transfer to grow out areas. Cleaning ropes of pest species, while not harming recently settle spat may be difficult to achieve. Until a reliable cleaning method is available, stopping the transfer of ropes between areas (particularly from areas where larvae of pest species are known to occur) would reduce the risk of spreading pest species.

5.5.4 Long-term control

Aquaculture

In Australia and New Zealand mussels (*Mytilus edulis* and *Perna canaliculus*) are grown on long lines suspended from floats in mid-water. Oysters (*Crassostrea gigas*) are grown on wooden racks or trays suspended above the substratum. These cultivation methods should prevent cultured bivalves being overgrown by sheets of *Musculista senhousia* (Willan 1987). *M. senhousia* does not withstand desiccation as its shell is extremely thin (Willan 1987). Therefore if it is found to foul mussel ropes, exposure to air for a period may be successful in killing *M. senhousia.* Corbulids are known to grow to high abundances in the substrate beneath marine farms. This could impact on other filter feeding shellfish species if densities are high enough to reduce local phytoplankton concentrations (*Potamocorbula amurensis* is known to have direct effects on the phytoplankton biomass in San Francisco Bay, USA; Alpine and Cloern 1992). Further research on impacts is required.

The introduced Pacific oyster *Crassostrea gigas* is an economically valuable aquaculture species in many areas but in others it is increasingly being regarded as an environmental pest. Dense aggregations of Pacific oysters on intertidal shores discourage recreational activities in addition to their environmental impacts. A primary method to reduce further spread of *C. gigas* is to prohibit new marine farms in areas outside the current distribution, an action taken by the States of Victoria and Tasmania. The introduction of a biological control agent using parasites or diseases is unlikely to receive public approval, and could have implications beyond the borders of this country. Genetic modification of oysters to produce sterile specimens unable to reproduce outside a farm environment may have more promise.

One technique currently used in the aquaculture industry is the production of triploid and tetraploid oysters (*Crassostrea gigas*, *C. virginica* and *Saccostrea commercialis*), mussels (*Mytilus edulis* and *M. galloprovincialis*), clams (*Ruditapes philipparum*) and scallops (*Placomen magellanicus*) (Davis 1997; Shatkin *et al.* 1997; Supan *et al.* 1997; Hand *et al.* 1998; Brake *et al.* 1999; Tweed and Guo 1999). Triploids are functionally sterile and hence put more energy into growth, allowing the marketing of a high quality product year round with higher meat yields (since they do not spawn). Methods of triploid induction in shellfish include temperature and/or pressure shock and the use of chemicals such as caffeine, cytochalasin B, or 6-dimethylaminopurine (Davis 1997; Brake and Davidson 1999). Triploid shellfish may be used as a way to farm introduced species without allowing wild populations to establish, especially since oyster spat is grown in hatcheries.

There are problems with the reversion of triploids back to diploids that need to be overcome before this method can be reliably implemented, since they are not 100% sterile and a normal diploid population must be maintained from which the triploid individuals can be produced. For example, a viable *C. gigas* population developed from a “sterile” triploid population introduced into Chesapeake Bay (Allen *et al.* 1999). Recombinant techniques hold more promise for the future, see below.

Biological control

Potential longer-term control measures include the use of biological control agents, the enhancement of native predator populations and genetic manipulation. Potential biological control technologies for the management of *Dreissena* spp are discussed by Molloy (1998) and include selectively toxic microbes and natural enemies found in the environment. Parasites are known from many of the mussel species discussed in this review, and some examples are given below. Introduced species tend to have lower parasite loads than native species in the invaded habitats. One example is the introduced mussel *Mytilus galloprovincialis* in South Africa where the native *Perna perna* has a high parasite load and is at a competitive disadvantage (Calvo-Ugarteburu and McQuaid 1998).

P. canaliculus has several natural parasites including the larval digenean trematode (*Cercaria haswelli*), the pea crab (*Pinnotheres novaezealandiae*), copepods (*Pseudomyicola spinosus* and *Lichomolgus uncus*) and an RNA virus (Jeffs *et al.* 1999). However, infection rates are low, with none causing significant mortalities in cultivated mussels and so are unlikely candidates for biological control agents for an introduced population of *P. canaliculus* in Australia.

Mytilopsis leucophaeta is parasitised by the dignean *Proctoeces maculatus* (Wardle 1980). Ciliates of the genus *Sphenophrya* and others in the order Rhynchodida parasitise *Corbula gibba*, and a wide variety of oyster and mussel species (Bower *et al.* 1994). Parasites of oysters include turbellarian flatworms, the protozoan pathogens *Bonamia ostreae* and *Perkinsus marinus* the copepods *Myticola orientalis* and *Myicola ostreae* and several viruses including a herpes-like strain (Minchin *et al.* 1993; Chu *et al.*1996; Boghen *et al.* 1999; Bower and Meyer 1999). The copepod *Myticola intestinalis* is known from *Mytilus edulis* (Minchin *et al.* 1993).

Various species of aquatic birds, fish and crustaceans are known to feed on *Potamocorbula amurensis* (Carlton *et al.* 1990), *Dreissena polymorpha* and *Corbicula spp.* (Boles and Lipcius 1997; Kelleher *et al.* 2000). Native crabs and algal grazing gastropods exerted significant mortality on oyster fouling communities in Alabama, USA (Rikard and Wallace 1997; Cigarria *et al.* 1998). Ducks and oystercatchers are known to feed on *Musculista senhousia* mats and may be responsible for some of the observed changes to the shape of mussel mats but are unlikely to cause major disruptions to existing mats (Yamamuro *et al.* 1998). However, in California predation on *Musculista senhousia* by the muricid gastropod *Pteropurpura festiva* contributes significantly to the resistance by the invaded community to the mussel and may locally prevent the establishment of dense mussel beds (Reusch 1998). This gastropod could be considered for use as a biological control agent and further research is required on host specificity and the effects of population enhancement on other species.

Biotechnology is an alternative approach to biological control that is developing rapidly and overcomes the need for species-specific parasites or pathogens. Advances in modern genetic technology means there are now a number of different molecular approaches for possible control and eradication of pest populations. CSIRO is currently involved in a multi-year, multi-institutional effort to develop repressible sterility techniques with applications currently targeted at Pacific oysters (Thresher and Grewe 1998).

Habitat manipulation

Creese *et al.* (1997) suggested that adverse environmental effects caused by *M. senhousia* are likely to be short-lived. In New Zealand, areas appear to be colonised by a large pulse of planktonic larvae that settle communally and a single cohort dominates mussel mats. The mats do not appear to be maintained by subsequent recruitment and the lifespan of a mat is determined by the longevity of the mussels (1-2 years); when older animals senesce the mat subsequently disintegrates. These population characteristics are consistent with other published accounts (Creese *et al.* 1997). While *Musculista* mats have a detrimental effect on existing sediment and infaunal assemblages (Crooks 1998), this effect is localised and only occurs where extensive beds are formed. Given the ephemeral nature of these beds, the environmental effects at a site are likely to be short-lived (Creese *et al.* 1997).

Bivalves with a byssal thread, such as the *Mytilopsis* sp. that invaded Darwin, and *Mytilus edulis* and require solid substrate to adhere to. Shoreline infrastructure that does not have a stable fouling community because it is either newly installed, cleaned, or in a polluted environment provides an opportunity for colonisation by an exotic pest such as *Mytilopsis* sp. Monitoring of these areas until the time that a stable fouling community has developed has the potential to reduce the risk of invasion, but further research is needed.

5.5.5 Summary

Control information for all bivalve molluscs is presented together because treatments would be similar although differences in susceptibility may occur. To date controls methods for molluscs concentrate on chemicals (see Table 2). Generally physical removal is seen as too environmentally damaging, unless it occurs at the very start of an invasion (eg. *Perna canaliculus* in the Port River, south Australia). However, there are many other techniques that have proven useful against *Dreissena polymorpha* in industrial plant situations including molluscicides, chlorine, copper sulphate, cathodic protection, desiccation, thermal shock, oxygen deprivation, acoustics, ultraviolet light, antifouling coatings and mechanical cleaning (Carpenter *et al.* 1972; Karande *et al.* 1982; McMahon *et al.* 1993; Claudi and Mackie 1994; Boyd 1996; Gnassia-Barelli *et al.* 1995; Jenner *et al.* 1997).

Although there are many chemicals effective against molluscs, the ability of bivalves to close their shells in the presence of noxious chemicals reduces the effectiveness of many of these. Polyquaternary ammonium compounds can act against molluscs at concentrations lower than that causing shell closure, but methods for maintaining effective concentrations in open environments will need to be explored. The main issue in chemical control is the reduction of impacts on local fauna, as most of the chemicals are not highly (or not at all) selective.

The ability of most molluscs to close their shells and resist desiccation prolongs life outside the water increasing the chances of successful translocation by a wide range of vectors. Byssal threads often provide a secure attachment for many molluscs.

Several potential biological control agents are identified. Ensuring the safety of native and commercial shellfish fisheries would be a major concern, if biological control was to be initiated. Future transgenic approaches could provide greater host-specificity.

5.6 Crustaceans (*Carcinus maenas*)

The European green crab *Carcinus maenas* has invaded the Eastern USA and Canadian Maritimes; Western USA; Victoria and Tasmania, Australia; South Africa and Japan. A voracious generalist predator able to colonise a variety of habitats, it has damaged fisheries, aquaculture and the native fauna. CSIRO Marine Research has used trapping to gather morphometric, demographic and parasite information, to promote understanding of its impacts and vulnerabilities in Australia. An international workshop in Tasmania, Australia, on managing *C. maenas* numbers suggested that two options were likely to be effective out of the many potential control options. The first was a large-scale program of physical removal, possibly in the form of a subsidised fishery, which may reduce impacts temporarily or in small areas where the crab is causing localised problems. The second was biological control (Thresher 1997).

A number of options have been suggested for control of the green crab in the USA, including visual searches, carbaryl spray, biological control, genetic alteration/ sterilisation, trapping, poison bait, fisheries/aquaculture and bounties. The top four prioritised control options were: targeted trapping, aquaculture, chemical control and biological control (Smith 1998). Of these four options, only trapping and poisoning are suitable rapid responses to a new incursion. Aquaculture is a response strategy not a control method and biological control requires further research at this time (Carr and Dumbauld 1999). Control and eradication of small, recently established populations of *C. maenas* on the West Coast of North America is considered feasible (Ruiz *et al*. 1998).

In December 2000 a single mature male portunid crab, *Charybdis japonica* native to Japan, Malaysia and China was found in the Port River adjacent to the Port of Adelaide. The crab was caught by a recreational fisher in a hoop net baited with squid. An extensive 3 day survey of the area by fisheries officers using crab pots and hoop nets failed to collect any additional specimens (Anon 2001).

5.6.1 Physical control

Physical methods used to control *Carcinus maenas* and other crab species include trapping, bounties, physical barriers, electrical pulses and the development of a crab fishery. Crabs are easily physically removed (via trapping) and can potentially be harvested in large numbers. The highest catch in a single trap in Tasmania has been 428 (Proctor and Thresher 1997). However, in areas of high abundances the large numbers of crabs and their high fecundity suggests that physical removal may only have a minor effect recruitment and do little to reduce crab impacts, especially if much of the environmental damage is caused by the juveniles that are too small to be caught in the traps.

Catch records from *Carcinus maenas* trapping in the US (Martha's Vineyard, MA) do not suggest obvious decreases in catch per unit effort and/or changes in population structure despite large catches; in some cases abundances increased (Walton 1997). In 1995 in Edgartown, USA a bounty was paid for green crabs as part of a response to the threat to commercial shellfish. Approximately 10 metric tons of crabs were trapped in the local salt ponds, which was presumed (but not proven) to improve survivorship of hatchery-reared scallops and hardshell clams (Walton 1997). In Washington where *C. maenas* has only been present for several years, catch per unit effort has declined as the population has apparently spread out in the estuaries making control efforts potentially more difficult (Carr and Dumbauld 2000b). In Tasmania, oyster farmers have trapped *C. maenas*, but little information is available on the effectiveness of this method, with catches suggesting a low return for effort (C. Proctor, CRIMP; pers. comm.).

In southern Europe there is a commercial fishery for *Carcinus maenas*, suggesting a market-driven harvesting scheme could be established that might reduce its impact in highly invaded areas (Thresher 1997). Up to 900 metric tons per year has been harvested from the fishery in France, Portugal and Spain and there is some evidence that the *C. maenas* population in Portugal declined due to overfishing (Gomes 1991; Svane 1997). Profitability could help mitigate the long-term, labour intensive components of a physical control program. Attempts to market *C. maenas* in the USA were unsuccessful, in the absence of a ready market. Developing a market would also be necessary if a commercial fishery were to be developed in Australia.

Trapping was considered to be the most environmentally sound approach for controlling *Carcinus maenas* in Washington State (Carr and Dumbauld 1999), although this assessment was based only on non-target effects of the control methods and not on their efficacy in controlling the crab.

One novel physical control approach is the use of sound pulses (104Hz) to control predation of the clam *Merceneria mercenaria* by crabs particularly the portunid, *Callinectes sapidus* (Cristini *et al.* 1994). In laboratory experiments, exposure to sound pulses significantly increased the time it took for the crabs to find food. Whether this would be practical in a field situation has not been assessed.

Trapping and electrical control measures were implemented to control the Chinese mitten crab *Eriocheir sinensis*, 15 years after it was first detected in Germany. Catches of crabs in 1936 and 1937 were 262, 600 kg and 190, 400kg respectively. (Panning 1939). Control methods used took advantage of the mitten crab's migratory behaviour that resulted in congregations of crabs at barriers such as weirs or dams during their upstream migrations. Trapping methods included traps on the upstream sides of dams that the crabs fell into them as they scaled the dam. In other locations troughs were constructed at the top of levees and the crabs were funnelled towards them and fell in and could not escape. Crabs would climb into barrels wrapped with wire netting or canvas placed below the dams and at one site over 113, 000 crabs were captured in a single day. Electrical screens installed on the river bottom and pulsed 30-40 times per minute were found to disable and then kill the crabs (Veldhuizen and Stanish 1999 and citations therein). The population declined to lower levels in the 1940's. Other mass occurrences have occurred in the 1950-60's and 1990's. Recent trapping of crabs has not been effective in controlling damage to river banks by crabs or preventing crabs feeding on trapped fish or fish stocks in commercial pond aquaculture. Crabs have been used as bait for eel fishing, to produce fish meal, cosmetic products and for human consumption (although there are risks to human health as the crabs are an intermediate host for the human lung fluke parasite in Asia) (Gollasch 1999; and citations therein (in German)). In California, fish collection facilities at pump stations on waterways have been severely impacted by huge numbers of mitten crabs. A travelling screen, a type of conveyor belt apparatus designed to move along the waterway upstream of the facility was found to remove 90% of mitten crabs while not harming the fish (Rudnick *et al.* 2000).

5.6.2 Chemical control

Poisoned baits were considered as one useful option for controlling *Carcinus maenas* in Washington State (Carr and Dumbauld 1999). The advantage of using poisoned bait (bait soaked in carbaryl) is that the method may not be as size-selective as traps and is potentially less expensive and easier to implement on a large scale. The primary disadvantage is mortality to non-target organisms due to either direct consumption of baits or exposure to chemical leachate from the bait. The use of poisoned baits for control of *C. maenas* was not approved under the Washington State Environmental Policy Act at the time of writing.

Carbaryl (eg. Sevin®) is a broad-spectrum organocarbamate that has been widely used for insect control in the terrestrial environment since DDT was banned in 1958 (USA). It does not bioaccumulate in the food chain and is relatively short lived in the environment (Dumbauld *et al.* 1997). Since 1963, the pesticide has been applied to intertidal oyster beds in Washington State to reduce populations a native burrowing thalassinid shrimp causing problems to oyster farmers. The shrimps reduce substrate compaction, causing oysters to sink into the substrate or to be smothered by resuspended sediment that impairs oyster growth. Carbaryl is applied (by helicopter) to oyster beds in Washington estuaries as a wettable powder and slowly hydrolyses into water and eventually breaks down to carbon dioxide. Carbaryl and its immediate breakdown product causes nervous system impairment resulting in behavioural changes, paralysis and death of the shrimp. The affects of carbaryl on non-target species have been extensively researched. Larvae of the Dungeness crab are effected, but it has a very low mammalian toxicity (Barahona and Sanchez-Fortun 1999; Dumbauld *et al.* 1997 and citations therein). Brooks (1993) found that carbaryl produced significant short-term impacts on non-target arthropods but within 51 days most populations recover to or exceed pre-spray numbers. Despite an attempt to develop an integrated pest management plan for the control of burrowing shrimp in 1992, no effective alternative control methods have been discovered and the carbaryl-based control effort has remained unchanged since 1963. Alternative methods proposed were changes to oyster culture techniques, mechanical control, enhancement of native predators, electrofishing, and modification of carbaryl application (Pitts 1993). While carbaryl removes adults from oyster beds it does not prevent the reinvasion of larvae from the plankton therefore repeated treatments are required (Feldman and Armstrong 1995).

The insect growth regulator Dimilin® (Diflubenzuron (1- (4-chlorophenyl)-3(2,6-difluorobenoyl)-urea) is lethal to the hatching larvae of the crabs, R*hithropanopeus harrisii* (Xanthidae) and *Sesarma reticulatum* in concentrations of 7-10ppb. No effects of Dimilin were apparent until the larvae started to moult; larvae were unable to complete moulting. Similar effects have been described for insect larvae (Christiansen *et al.* 1978).

Attempts to control the predation of clams *Merceneria mercenaria* by crabs particularly *Callinectes sapidus* (a Portunid) have included mechanical separation and chemical control. Chemical control agents such as saturated salt solutions, quick lime, copper sulphate, chlorinated hydrocarbons and insecticides have all been used with varying success (Cristini *et al.* 1994). Environmental problems associated with the use of chemicals to control crabs are the same as those for other target species already discussed.

Various studies have been done on the blue crab *Callinectes sapidus* in the USA to examine the effects of environmental pollutants including pentachlorophenol (PCP) (a pesticide), benzene and dimethylnaphthalene (aromatic hydrocarbons), and copper and cadmium (heavy metals) (Cantelmo *et al*. 1982; Coglianese and Neff 1982; Johns and Miller 1982). PCP is highly toxic to most living organisms although marine and freshwater crustacean appear to be moderately tolerant of PCP and its sodium salt (NaPCP) and is no longer used as a molluscicide as it is damaging to the handler and the environment (Coglianese and Neff 1982; Perrett and Whitfield 1996). When exposed to low doses of benzene and dimethylnaphthalene juveniles of *Callinectes sapidus* were able to maintain hemolymph concentrations despite an overall depression in metabolism. However exposure to benzene considerably increases the time to complete a moult cycle (from 33 days normally, to 50 days) (Cantelmo *et al*. 1982).

5.6.3 Management of spread and translocation

Vectors associated with the translocation of *Carcinus maenas* have not been thoroughly investigated, however, as it can survive for considerable periods of time out of water, especially in protected or enclosed spaces where humidity remains high, it is safe to assume that there are many potential modes of translocation. The crab has been spread by the movement of shellfish stock, particularly oysters in Tasmania (R. Martin, CRIMP, pers. comm.). Education of boaters and commercial shellfish growers could assist in reducing the rate of spread. However, before major restrictions on operations were considered, the relative contributions to spread by anthropogenic and natural larval drift (larvae are in the plankton for weeks or months depending on temperature) would require identification. Reduction of the risk of sudden major range extensions would be the most important aspect of risk reduction.

5.6.4 Long-term control and management

Aquaculture

The impact of *Carcinus maenas* on shellfish aquaculture facilities in its native Europe and in invaded regions of the USA is well documented (Ruiz *et al.* 1998). However, in Tasmania at present *C. maenas* appears to be having little impact on aquaculture. This can probably be attributed to the fact that in Tasmania oyster and mussels are farmed “off the bottom”. Oysters are grown in mesh baskets on racks one metre off the bottom, mussels are grown on long lines suspended vertically in midwater without bottom contact. The benthic infauna upon which *C. maenas* feeds is abundant in the sediments below the oyster racks and birds prey heavily on crabs which climb up the racks (Proctor 1997). Infaunal clam fisheries are restricted to only a very small area compared to their prevalence in the USA but *C. maenas* is known to have an effect on near-shore bivalve fisheries, such as the clams *Katelysia* in Tasmania (Proctor 1997).

In the USA, commercial shellfish growers use mesh nets (8-45mm diagonal mesh) over shellfish stocks to prevent *C. maenas* preying on juvenile oysters (15-47mm shell length). Oysters larger than 50mm shell length are relatively safe from attack by *C. maenas.*

Biological control

Longer-term options for the control of *Carcinus maenas* include biological control agents, enhancement of native predator populations and genetic or molecular controls. *Carcinus maenas* is host to a broad range of parasites and pathogens, some of which can castrate or kill their green crab host (Brock and Lightner 1990; Torchin *et al.* 1996; Goggin 1997). Studies on biological control agents for *Carcinus maenas* have been carried out in the US and Australia. The rhizocephalan parasitic castrator, *Sacculina carcini* has been found to infect native Australian crabs (in the family Portunidae) as well as *C. maenas* in Australia and the USA in laboratory trials (as well as other portunids in its native range in Europe) (Lafferty and Kuris 1996; Minchin 1997; Murphy and Goggin 2000; Thresher *et al.* 2000). This raises the questions of what level of host specificity is desirable/necessary for a biological control. *S. carcini* has severe and lasting effects on the growth, morphology, physiology and behaviour of the host crab and castrates both males and females (Thresher *et al.* 2000). Further research is needed on host specificity, efficacy and infection rates.

A different species of sacculinid barnacle (*Loxothylacus panopaei*) is known to parasitise the xanthid crab *Rhithropanopeus harrisii* where both species are introduced into Chesapeake Bay, USA (Alvarez *et al.* 1995; Grosholz and Ruiz 1995), but the rate of infection is very variable ranging from 0-83% in different areas (Hines *et al.* 1997). This rhizocephalan appears to be more host-specific than *Sacculina carcini* and is only known to infect six other species of xanthid crabs. Other parasites found in the green crab requiring further examination include viruses, dinoflagellates (*Hematodinium perezi*), ciliates, egg-predatory nemerteans (*Carcinonemertes epialti*), epicaridean isopods (*Portunion moenadis*), nematodes and trypanorhynch tapeworms (Torchin *et al.* 1996; Goggin 1997; Hoeg 1997; Kuris 1997; Kuris and Gurney 1997).

Enhancing native predator populations is one method proposed to control introduced species. A number of predators are known to eat larval, juvenile and adult *C. maenas* including fish, crabs, birds, seals, and otters (Dumas and Witman 1993; Cohen *et al.* 1995; Dumbauld and Kauffman 1998; Ruiz *et al.* 1998). Predators of the Chinese mitten crab *Eriocheir sinensis* include fishes, waterfowl and aquatic birds in Germany (Panning 1939), and white sturgeon, striped bass, catfish, bullfrogs, loons and egrets in San Francisco Estuary, USA. Fishes, otters, raccoons and wading birds are also likely to consume mitten crabs (Veldhuizen and Stanish 1999). Native predator enhancement as means to control *C. maenas* or *E. sinensis* has not been examined.

A variety of genetic/molecular control measures have potential but none of these have been developed or adequately tested for marine organisms (Grewe 1997). Methods used for population control in freshwater or terrestrial systems include immunocontraception, ploidy/chromosomal manipulation and gender manipulation (release of sterile males/controlling sex composition of populations), hormonal treatment and "inducible fatality" genes via transgenic techniques (Grewe 1997; Ruiz *et al.* 1998). As with biological control agents for marine pest species, genetic/molecular engineering approaches to control green crabs are not immediately available and would require considerable further development (Ruiz *et al.* 1998).

5.5.5 Summary

The European green crab *C. maenas* is an invasive species damaging marine environments and shellfish fisheries internationally. Physical removal by a variety of traps is common, however its efficacy does not seem high. A commercial fishery could help reduce crab numbers if a market was found (and the risks involved in encouraging commercial exploitation of a pest species could be resolved). Chemical control using poisoned baits seems a viable technique for removing adults in localised areas; carbaryl (Sevin) is one compound routinely used for control of other crustaceans on oyster beds in Washington State. Repeated applications would be required to maintain control. More specific "arthropod" moult regulators may also be useful and have higher specificity than carbaryl, but they have not been extensively tested. Suspending grow-out racks or ropes above the bottom can protect aquaculture grown shellfish from benthic predators such as crabs. There are several options available for long-term control, including parasites, parasitic castrators, enhancement of native predators and genetic or molecular techniques. None have been adequately assessed.

5.7 Polychaetes (*Sabella spallanzanii*)

Sabella spallanzanii has been present in Australian waters since the 1960s (Giangrande and Petraroli 1994; Clapin and Evans 1995). *Sabella spallanzanii* fouls hard structures such as wharf piles, channel markers breakwalls and ship hulls and is also able to form meadows on soft sediments. Scallop fishers in the Geelong Arm of Port Phillip Bay, Victoria first noticed the fan worm *S. spallanzanii* in their catches in 1993. By 1996, catches of the fan worm had increased to the point at which they clogged the scallop dredges and increased catch sorting time. *S. spallanzanii* is also reported to hinder the snapper fishery through interference with longlines (Ward and Andrew 1996). However, Clapin and Evans (1995) found no evidence that *S. spallanzanii* was directly threatening any fishery in Cockburn Sound in Western Australia.

No control methods for benthic worms, such as *S. spallanzanii*, were found in the reviewed literature. The broad habitat range of *S. spallanzanii* and its current wide distribution in Australia complicates the development of effective controls; biological control offers the most likely option for long term control. Control options for spionids and sabellid polychaetes that bore into shellfish are documented but as these pests have a different habitat to *S. spallanzanii* the controls may not be readily transferable.

A population explosion of an epifaunal polychaete, *Chaetopterus* sp. is currently a problem in northern New Zealand. The 6 cm worms build their papery tubes, up to 20 cm in length, at an alarming rate, and cement them together to form a carpet-like layer over huge tracts of seabed, suffocating other marine life, usually in depths of 30 to 40 m. It forms meadows on sand bottoms and almost exactly mirrors the *Sabella spallanzanii* problem in Australia. Scallop fishers catch vast quantities of worm tube instead of scallops in their trawls and the industry is suffering (G. Read, NIWA, pers. comm.; Beston 2000a, b). Since scallop fishers discovered the worm in 1997 near Whitiangi it has spread as far north as Houhora, around the Whangarei Heads and the Whangaparaoa Peninsula and as far south as Tauranga and is spreading rapidly throughout the Hauraki Gulf. Its sudden appearance in such large numbers, its dominance close to the main shipping lanes into Auckland and the fact that it has spread so rapidly in the past three years strongly suggests an invasive species (Dr Bob Creese, Auckland University, pers. comm.). The National Institute of Water and Atmospheric Research (NIWA), Auckland University and other New Zealand authorities are now working on various aspects of the worm. It is unlikely to be easily controlled and it is impossible to predict whether high populations will continue (G. Read, NIWA, pers. comm).

5.7.1 Physical control

Physical removal may be possible if an incursion is detected before reproduction occurs. Minimum size at maturation in the Mediterranean is 15 centimetres (Giangrande and Petraroli 1994; Giangrande *et al.* 2000) but *S. spallanzanii* in Port Phillip Bay, Australia reaches maturity at 5 centimetres (Currie *et al.* 2000). *S. spallanzanii* has external fertilisation and large females can produce approximately 50000 eggs over an extended autumn/winter period. Data on the distribution of *S. spallanzanii* in Port Phillip Bay show a general clockwise expansion of the worm that is consistent with water circulation patterns (Currie *et al.* 2000). This highlights the influence of planktonic larvae in the spread of this introduced species. Care needs to be taken during physical removal to not induce spawning.

Physical removal is being used by NSW Fisheries to control the outbreak of *S. spallanzanii* in Eden harbour. The worm was found in Eden in 1997 during a CRIMP port survey. At that time, two worms were located and removed. Since then regular monitoring has occurred using SCUBA divers to physically remove any *S. spallanzanii* found in the harbour. The appearance of new individuals between removals is attributed to reintroduction of specimens by vessels travelling to Eden from Port Phillip Bay rather than an established breeding population (C. Hewitt, CRIMP; pers. comm.). Care and diver education is of primary importance in this program because a similar-looking native fanworm, *Sabellastarte,* is also present in the harbour and around Australia.

Physical removal by divers is not logistically possible for infestations extending over large areas. Dredging or similar mechanical techniques that could fragment the fanworm are not recommended because *Sabella* is known to regenerate damaged body parts both anteriorly and posteriorly (Berrill 1931; Kiortsis and Moraitou 1965; Clapin and Evans 1995). Decapitation (removal of crown, collar and part or the entire thorax), whether due to predation or autonomy, was found to have very little effect on the irrigation behaviour of *S. spallanzanii* and lost body parts can be regenerated, while the worm continues to function (Wells 1951). Scallop fishers in the Geelong Arm of Port Phillip Bay may have contributed to the rapid spread of the fanworm through the Bay by throwing back fragments retained on clogged dredges (Ward and Andrew 1996).

Hot water, as used in the *Exxon Valdez* oil spill clean up in Alaska has the effect of cleaning intertidal and subtidal regions, of biota as well as oil (Mearns 1996), and could be used against *S. spallanzanii* on harbour structures (wharf piles, channel markers breakwalls and ship hulls). However, specimens can survive short period of moderately high temperatures (12 hours at 30°C; Clapin 1996), so suitable protocols would have to be developed.

Abalone hatcheries in California are now plagued with an introduced shell-boring sabellid polychaete, *Terebrasabella heterouncinata* (4-5 mm length), that is also a problem in its native South Africa. Efforts to exterminate the sabellid have focused on physical controls such as coating shells with wax or other substances to smother the worms (Oakes *et al.* 1995); freshwater baths (Bower 1997); or altered water temperature. Exposing sabellid-infested abalone to temperatures near but below their thermal limits (48 hours at 28.5 °C) killed all lifestages of the sabellids while causing only minor abalone mortality (Leighton 1998). However, lowering water temperatures was unsuccessful in controlling the sabellid and resulted in decreased abalone production (Oakes and Fields 1996). Ultrasound micro-cavitation treatment of infested abalone for 1-10 minutes killed all sabellid eggs and juveniles and destroyed feeding crowns of a high proportion of adult worms impairing feeding and reproductive activity (Loubser and Dormehl 2000).

A range of treatments exists for oysters infested with boring spionid polychaetes. These include fresh water exposure and heated seawater immersion. The effectiveness of the freshwater (tap) exposure was increased if the oysters were precleaned using high pressure water jets. When oysters were exposed to water temperatures of 70°C for 40 seconds the infesting spionid polychaetes were killed but the core temperature of the oysters did not exceed 24°C, which is close to the maximum sea temperature they would experience in the natural environment. (Nel *et al.* 1996).

5.7.2 Chemical control

A review of the toxicological studies with polychaetes was conducted by Reish and Gerlinger (1997). This covered 20 families of polychaetes and the toxicants included metals, petroleum hydrocarbons, detergents, pesticides, contaminated sediments and radiation. *Eudistylia vancouveri* is a large, robust sabellid polychaete that lives attached to pylons or in intertidal to subtidal sediments on the west coast of North America; this species is ecologically similar to *S. spallanzanii.* When *E. vancouveri* is exposed to copper in seawater at a level above the threshold limit for copper accumulation it accumulates increasing amounts of the metal with time, especially in the branchial crown. At higher than threshold concentrations, the radioles (gills) of the branchial crown are chemically injured and become necrotic (Young *et al.* 1981).

Efforts to exterminate the boring sabellid, *Terebrasabella heterouncinata* in aquaculture facilities by chemical means have including water-soluble toxic substances and microencapsulated toxins (Shields *et al.* 1998).

5.7.3 Management of spread and translocation

S. spallanzanii is known to rapidly colonise recently cleared or newly submerged hard surfaces and can be transported as hull fouling on slow moving vessels or on aquaculture lines (Clapin and Evans 1995). Translocation risks would be reduced by regular cleaning and adequate antifouling of fishing and recreational vessels, and further reduced if hulls were checked before moving out of infected into uninfected areas.

In some localities in Sardinia, Italy recreational fishermen regard *S. spallanzanii* (known as "Tremuligione amaro") as a particularly suitable bait for catching large Sparidae. Apparently there is potential for a larger bait market for this species in Italy based on some preliminary tests conducted with amateur anglers in Italy (Gambi *et al.* 1994). The spread of *S. spallanzanii* in South Australia between West Lakes and Bakers Inlet, Port Adelaide and off the Adelaide metropolitan coast is attributed by some researchers to fishermen using them for bait and dumping excess overboard (K. Gowlett-Holmes, CSIRO; pers. comm.). Articles in the local newspaper (The Advertiser) by South Australian Museum/SARDI personnel recommended that fishermen should not dump such worms used as bait while at their fishing locales. While suitable for bait in their native range, *S. spallanzanii* is unsuitable for bait in introduced habitats and its use should be discouraged.

5.7.4 Long-term control and management

Aquaculture

Control of *S. spallanzanii* on aquaculture structures (eg. commercial mussel lines and oyster spat baskets) moved from infested sites require further investigation. Possible methods include exposure to freshwater and air. Recent work by mussel growers in Port Phillip Bay indicated that 24 hours air exposure kills many epiphytic biota on mussel ropes (Garnham 1998). However there is always likely to be some survival of individuals in amongst the denser clusters of mussels.

Biological control

Biological control may offer the most likely long-term control option for *Sabella spallanzanii* as physical and chemical control methods are complicated by the diverse habitats occupied (fouling on wharf pylons etc. in open waters and mats on the sediments) and its high fecundity and planktonic dispersal. No specialised parasites or signs of pathogens have been found to date on *S. spallanzanii* from Victorian waters (C.L. Goggin and N. Murphy, CRIMP; pers. comm.). This is to be expected if *S. spallanzanii* was introduced as planktonic larvae in ballast water or as a small number of parasite- and disease-free individuals as hull fouling. An adventitious survey of *S. spallanzanii* in Italy found no parasites (C.L. Goggin, CRIMP; pers. comm). Gotto (1960) made observations of a parasitic copepod *Sabelliphilus elongatus* found on the branchial crowns of the fan worm *S. pavonina*. Eighty eight percent of 26 specimens of *S. pavonina* surveyed were infected with the copepod – up to 18 copepods were on a single host. Both polychaete and copepods thrived in the laboratory. A related copepod *Sabelliphilus sarsi* is found on the body of *S. spallanzanii* when mature, and on the crown as juveniles. *Sabelliphilus sarsi* does not appear to harm its host and therefore may not be an effective biological control agent (Carton 1967).

Polychaetes serve as hosts for a range of parasites including bacteria, viruses, ascetosporans, apicomplexans, microsporidians, ciliates, algae, mesozoans, trematodes and copepods. Parasites are known for species within at least 12 polychaete families including the Sabellidae (Kozloff 1961, 1965; Raftos and Cooper 1990; Douglass and Jones 1991; Atkinson unpublished report). The use of parasites for biological control of polychaetes was not discussed.

Some individuals of *S. spallanzanii* collected in Cockburn Sound, Western Australia lacked crowns, possibly as a result of predation. Leatherjackets are known to attack specimens in aquaria, although this has not been observed in the natural environment in Australia (Clapin and Evans 1995). Terrestrial biocontrol experts now shun introducing general vertebrate predators as biological control agents; generalist vertebrate predators have led to some of the worst biological control programs with substantial non-target damage. Enhancing native predators would not have the same irreversible risks, however the efficacy of this approach requires further research.

5.7.5 Summary

Sabella spallanzanii is dispersed as a planktonic larval form, naturally and in ballast water (and possibly other water bodies). In its adult form, it can spread as a fouling organism or from fragments or whole animals discarded as fishing bait. No specific control methods for *S. spallanzanii* were found. Physical removal is complicated by the ability of fragments to regenerate. Hot water treatment may be useful in some instances depending on the size of the infestation and the habitat occupied. Although there was little research available, copper in solution was noted as one chemical that would probably damage this worm. There are several options available for treating polychaete-infected shellfish in aquaculture operations – hot water appearing to be one of the more feasible options. Ultrasonic techniques bear further investigation, and could even have potential outside aquaculture operations. Long-term control using biological control agents has not been fully explored. Although there are signs of predation by native fish in Cockburn Sound, more research is required to determine whether this provides a viable biological control option.

5.8 Bacteria (*Vibrio cholerae*)

Vibrio cholerae is rather a public health issue than an introduced species problem. *V. cholerae* is the causal agent of cholera, a diarrhoeal disease with severe health consequences when access to health care is limited. Cholera is transmitted through ingestion of faecally contaminated food and beverages. Cholera is predominantly found in areas with poor sanitation and hygiene. Cholera is a serious epidemic disease that has killed millions of people and continues to be a major health problem worldwide. The seventh pandemic began in 1961 in Indonesia and spread to Africa, Mediterranean, and Eastern Europe, reaching Latin America in 1991 (Epstein 1993). Persons travelling in cholera-affected areas should not eat food that has not been cooked and is not hot (particularly fish and shellfish) and should drink only beverages that are carbonated or made from boiled or chlorinated water (Centre for Disease Control and Prevention 1995).

Transmission or importation of cholera cases in Europe, North America, Japan and Australia is controlled by effective surveillance, early diagnosis and prompt treatment. Outbreaks are contained by effective sanitary regulations, abundant domestic water, and effective disposal of human wastes and sewerage treatment plants (Kumate *et al.* 1998). The likelihood of a major cholera outbreak in these countries is slight since the disease is associated with primitive hygiene conditions. Continued education on personal hygiene, and reduced pollution of waterways by sewage will continue to keep the risk of infection low.

Strategies for eradicating cholera from developing countries are based on improving living conditions and public education. Chemoprophylaxis and international trade barriers have proven ineffective to contain cholera transmission, and vaccination is not recommended. Therefore, recommended interventions leading to cholera control are focused on health education, hygiene and sanitation:

- Provision of drinking water and protection of stored water;
- Good hygiene practices when cooking food, reheating food if prepared hours previously;
- Prohibiting irrigation of harvest beds with sewerage waters;
- Health education for the population and specifically in schools and for teachers;
- Sanitary regulation of foods and beverages; measurement of residual chlorine in municipal and domestic waterpipes; and training and surveillance of street food vendors; and
- Intensive collaboration with other governmental agencies concerned with agriculture, tourism, education and health institutions.

The task involves environmental sanitation, sensitive surveillance systems, appropriate case detection and clinical management, food safety, health education. A reasonable strategy based on sanitary interventions supported by technical resources should eliminate cholera as a public health threat in the years to come (Kumate *et al.* 1998).

V. cholerae can exist as free-living bacteria or in association with phytoplankton, zooplankton, crustaceans and molluscs in coastal and estuarine environments (DePaola 1981; Sinderman 1996). The capacity of the organism to adapt to changes in salinity, temperature and the availability of nutrients means that *V. cholerae* can successfully occupy a variety of aquatic habitats (Wai *et al.* 1999). *V. cholerae* is endemic to many waterways in the world and these act as reservoirs for reinfection to other regions given favourable conditions for the bacteria. In other words outbreaks can occur in the absence of faecal contamination when proper food handling techniques are not used (Sinderman 1996). Another problem is that *V. cholerae* can exist as a viable but non-culturable (VBNC) form that is difficult to detect and can remain dormant until conditions are favourable. *V. cholerae* can recover from this state in the human gut and after increases in temperature, although there may be a period after which the cells cannot recover (Colwell *et al.* 1996; Oemcke 1999). This will cause a problem with the control of cholera worldwide.

There have been three cases where ballast water or other non-potable waters discharged by ships have been considered as the vector for the introduction of the toxigenic cholera bacterium into new areas. The first was the introduction of cholera into Latin America where a cargo ship was implicated but not proven to be the source. The second was the isolation of *V. cholerae* in oysters and ballast waters on the US Gulf coast (McCarthy and Khambaty 1994). The third, a survey of ballast water of 15 ships in Chesapeake Bay, found a high prevalence of two serotypes of *V. cholerae* (01 and 0139). However the presence of the introduced strain in the US Gulf Coast was transitory and suggests that non-indigenous epidemic strains do not readily establish (Desmarchelier and Wong 1998). Analysis of

Chesapeake Bay water now indicates the presence of these serotypes in the natural environment (Rawlings *et al.* 1999). The discharge of ballast water containing *V. cholerae* 01 or 0139 into Australian ports could cause contamination of nonpotable waters. A public health risk will ensue if raw food harvested from these waters is contaminated or cooked food is recontaminated by this water (eg. by washing). Such incidences have a significant impact on seafood and its associated industries. In America and other parts of the world, consumption of contaminated seafood has been a common vector for transmission of cholera (Desmarchelier and Wong 1998).

However, the risks of cholera epidemics in Australia are minimal given the current public health infrastructure. Australia does not receive significant amounts of ballast water from regions with a high-risk of cholera contamination and the introduction of *V. cholerae* is considered to be unlikely. There is little evidence that it would establish in our environment or cause severe public health impacts provided our current level of public health is not compromised (Desmarchelier and Wong 1998).

The current methods proposed for treatment of ballast water will have little impact on the presence of *V. cholerae*. Filtration will reduce the number of *V. cholerae* by the removal of attached cells, although planktonic cells will not be removed by coarse filtration. Biocides will reduce the numbers present provided the organic content is low. However, bacteria internalised in or attached to other biota or biofilms will be protected and require higher concentrations and longer exposure times of the biocides and/or primary removal before disinfection. Heat treatment at 37°C and 45°C will not eliminate *V. cholerae* and if nutrient concentrations are favourable growth may actually occur (Desmarchelier and Wong 1998).

Monitoring ballast water for *V. cholerae* is not considered to be an effective means for the control of the introduction of cholera into Australian waters. Disease surveillance was recommended by the World Health Organisation as the best indicator of cholera presence. The World Health Organisation recommends the surest way to protect communities from cholera is to reduce the chance of consuming contaminated food and water by ensuring safe water and food supplies and the safe disposal of human bodily wastes (Desmarchelier and Wong 1998).

5.8.1 Summary

Cholera is present in many waterways worldwide and thus can be transported to Australian ports in ballast water. Current methods proposed for treatment of ballast water will have little effect on *V. cholerae* as bacteria internalised in or attached to other biota or biofilms may not be susceptible to most treatments. The surest way to protect communities from cholera is to reduce the chance of consuming contaminated food and water by ensuring safe water and food supplies and the safe disposal of human bodily wastes.

5.9 Other taxa

Several taxa containing pest species are not included in the review as they are not on the target list (although present in Australia) and few attempts have been made to control them (eg. bryozoans, hydroids, gastropods and ascidians). There are for example no introduced predatory gastropods in Australia that cause problems for the aquaculture industry such as those that are having impacts on the oyster industry in the USA and UK (ie. *Urosalpinx*, *Rapana* and *Crepidula*). Several other taxa not on the target list but present in Australia include introduced fish (eg. European carp, *Cyprinus carpio*, and the gobies *Acanthogobias flavimanus* and *Tridentiger trigonocephalus*), ricegrass (*Spartina* spp.) and wood boring isopods (*Limnoria* spp. and *Sphaeroma* spp.). Control methods do exist for these species and are briefly outlined below.

5.9.1 Fish

Many fish species have been introduced around the world – many deliberately for aquaculture and sports fisheries (eg. brown and rainbow trout, European carp), bait fish and water treatment (eg. European carp), aquaria escapees or releases (eg. goldfish, cichlids) or accidentally introduced by shipping (eg. yellow finned goby, ruffe). A small number of fish species have been introduced for biological control purposes, and have been very damaging to native biodiversity – mosquito fish, *Gambusia affinis* (for mosquito control) and grass carp *Ctenopharyngodon idella* (for aquatic vegetation control)(Courtenay 1993). Other exotic fish have introduced exotic diseases into native fish populations with devastating results.

A review of control methods by Meronek *et al*. (1996) divided fish control treatments into four categories: physical removal and reservoir drawdowns; chemical applications; stocking of fish for biological control; and any combination of methods. Several isolated populations of introduced fish species in Florida have been eradicated including the pirambeba (*Serrasalmus humeralis*) and the three-spot cichlid (*Cichlasoma trimaculatum*) (Courtenay 1997). A workshop in Albury, Australia in 1996 explored the options for controlling carp *Cyprinus carpio* in Australian waterways including environmental rehabilitation, physical removal, chemical control, biological control agents and genetic manipulation (Roberts and Tilzey 1997). Leigh (1998) estimated that instituting a ruffe control program in the Great Lakes would yield estimated net public savings of $513 million for the USA over the next five decades. Current control measures recommended to prevent the spread of fish species in ballast water are the mid-water exchange or other suitable treatment of the ballast water and by antifouling treatment of floating objects that can provide a transport vector (Skora *et al*. 1999)

5.9.1.1 Physical control

The use of nets (seines, midwater trawl nets, gill nets, fyke nets and dipnets) and permanent traps are unsuccessful in capturing all individuals of a population (juveniles escape) and impractical and too costly for carp and ruffe (Busiahn 1996; Barnham 1998a). The use of radio-tagged individuals in aggregating fish species allows a large proportion of the population to be successfully captured. This method is currently being trialed by the Tasmanian Inland Fisheries Service in an attempt to eradicate carp by targeting radio-tagged “Jonah” fish, or removing only females and returning radio-tagged males to aggregate remaining females (J. Diggle, Inland Fisheries Service, Tasmania, pers. comm.). Electro-fishing is a method of collecting and controlling fish in freshwater. Electro-fishing has been used to control carp, and for collecting specimens of lampreys, trout and salmon. Lowering water levels (eg. in farm dams, lakes or reservoirs) can be used to control fish but causes non-specific species mortality. As carp spawn in shallow water, lowering water levels after spawning can cause desiccation and mortality of European carp eggs (Barnham 1998a). Anon. (1997) describes an attempt by local businessmen to reduce carp damage in the Murray-Darling catchment by making fertiliser out of the fish (Carp-Fert).

5.9.1.2 Chemical control

The application of a piscicide is the only method other than dewatering that will extirpate entire populations of fishes (McClay 2000). Rotenone has been used as a piscicide in a powder or liquid form, and as oral baits by fisheries managers for more than 50 years. Problems associated with rotenone use include non-specific fish mortalities downstream from the application sites, persistence of treatment chemicals in water and air and detrimental human health effects. For these reasons rotenone use has been prohibited or restricted in many places. Rotenone is not effective in systems subject to currents such as the marine environment and is most successful in small static waterbodies (McClay 2000). Rotenone has been used to control small isolated populations of European carp, *Cyprinus carpus* in Australia and to eradicate highly predatory exotic species such as white bass (*Morone chrysops*) and northern pike (*Esox lucius*) from Californian reservoirs (Barnham 1998a; AFS 2000). The use of chemicals to kill carp in Victoria has proved to be expensive and rarely effective.

Other chemicals besides rotenone trialed to control carp in Victorian waters include Santobrite (sodium pentachlorophenate) and Limil (slaked lime) (Barnham 1998a, 1998b).

Fish toxicants registered for use in the USA include rotenone, antimycin, TFM (3-trifluoromethyl-4-nitrophenol) and Bayluscide, but the latter two are restricted use lampricides and require special permits for use (Busiahn 1996). TFM has been used successfully in freshwater habitats to control lampreys (in Canada) and ruffe (in USA). Ruffe is considerably more sensitive to TFM than many native fish and TFM could possibly be used to control populations with limited adverse effects on native species. TFM meets all safety requirements by the American EPA and Environment Canada including no long-term effects on the environment, human and animal life. It does not leave persistent residues or react with other new chemicals to create hazardous substances (Boogaard *et al.* 1997; Simmons 1998). Bottom release formulations of granular bayluscide and antimycin may be useful in treating localised concentrations of fish (Dawson *et al*. 1998)

Pesticide contaminated diets fed to shrimp, crabs and fish have caused significant and rapid mortalities as well as impairing fish reproduction (Sinderman 1996) and are likely to have a big environmental impact to non-target species.

5.9.1.3 Long-term control and management

One biological control method for introduced carp considered by Victorian fisheries managers in the 1970s was the introduction of a virus "Spring viraemia" (*Rhabdovirus carpio*). Initial trials indicated it was specific to carp but too many risks were associated with the introduction of this rabies-like virus and research was abandoned. (Barnham, 1998a). Several new viruses of carp have been detected recently in Israel and the U.S. suggesting that additional viruses for biological control may now be available (Hedrick *et al*. 2000).

Stocking of certain predatory fish species to control nuisance fish is not often successful, since they are often generalist predators and impact upon native species as well. However this method is more likely to succeed in combination with other control methods (Meronek *et al*. 1996).

Advances in modern genetic technology means there are now a number of different molecular approaches for control and possible eradication of pest populations. These include chromosomal manipulation, gender manipulation (via hormones and transgenic methods), immunocontraception and the introduction of inducible fatality genes via transgenic techniques (Grewe 1996; Davis *et al.* 1999). CSIRO is currently involved in a multi-year, multi-institutional effort to develop repressible sterility techniques with applications currently targeted at zebrafish (as a carp equivalent), Pacific oysters and mice (Thresher and Grewe 1998).

5.9.1.4 Summary

Fish have been controlled and/or eradicated from relatively small isolated freshwater bodies, using chemicals or dewatering. Physical removal has not succeeded in eradicating fish populations but may support other approaches. Control of fish in open water – freshwater or marine – has yet to be successfully attempted. New developments in molecular biology may provide options for control of open populations.

5.9.2 Aquatic vegetation (Spartina spp.)

In southern Australia the introduced rice grass species *Spartina anglica, S. alternifolia* and *S.* x *townsendii* have been used to stabilise mud banks but are now considered a nuisance. *Spartina* spp. were also introduced to temperate estuaries in New Zealand, USA, UK, Netherlands, France and China (Rash *et al.* 1995; Daehler and Strong 1996; Forrest *et al.* 1997; Kriwoken and Hedge 2000). *Spartina* rhizomes and roots grow to a depth of three metres and eradication attempts have included physical removal, cooking by solarisation under plastic sheets and application of herbicides (RGAG 1998; Faithful, 2000). At present, there are no recognised cost effective control techniques for the treatment of *Spartina* infestations larger than one hectare, other than the use of herbicides (Kriwoken and Hedge 2000).

Spartina control in Tasmania is complicated by legislative confusion over responsibility for the coastal zone with approximately 10 state agencies and 8 state Acts involved. *Spartina* can be legally imported in Tasmania or transported between locations within Tasmania as it is not listed as a weed species on the Tasmanian 1964 Noxious Weeds Act or the 1908 Commonwealth of Australia Quarantine Act (Kriwoken and Hedge 2000).

5.9.2.1 Physical control

Physical removal by pulling and digging is unlikely to succeed once clones/clumps exceed ~15 centimetre diameters. Mechanical excavation may be effective in areas where suitable access is permitted (and substrate is stable enough) although problems exist with the disposal of material and impacts and modifications to the environment (RGAG 1998). Smothering using black plastic or weed matting kills plants by inhibiting photosynthesis and increased temperatures. This has been used successfully in field experiments to control rice grass but treatment requires an extended period (up to 6 months) and kills all plant species (non-selective). Hence, physical removal and smothering although relatively effective, is time consuming and labour intensive and limited to small areas (<1 hectare) (Kriwoken and Hedge 2000).

In the UK, physical disturbance was investigated as a possible control method. This involved disturbance of the sediments by a lightweight tracked vehicle until the *Spartina* clumps were dislodged and buried with the sediment. There was no evidence of impacts to the infauna and the method was thought to be an appropriate for *Spartina* control in tidal flats (Frid *et al.* 1999). Preliminary experiments using mowing as a control method for *Spartina anglica* and *S. alternifolia* using sickle bar mowers or weed eaters in Washington, USA, had variable success depending on the time of year (Bentler 1998). Mechanical harvesters and hydraulic excavators are used in freshwaters to control excessive macrophyte growth. Nets are also used in as a barrier in waterways to prevent the active drift of vegetative fragments of aquatic weeds created during mechanical harvesting (Moreira *et al.* 1999).

Steam treatment (~100°C) of rice grass for 20-30 seconds per stand has been used in New Zealand with relative success. The method is non-selective and there are problems associated with accessibility and maintenance of high temperatures (Rash *et al.* 1995). Other attempts to control *Spartina* infestations found to be ineffective and caused increased environmental degradation include grazing by sheep and cattle and burning. Annual burning has been found to increase photosynthetic ability and growth of *Spartina pectinata* in Kansas, USA wetlands (Johnson and Knapp 1993).

A freshwater example that used both mechanical and chemical means is the removal of the invasive reed species *Phragmites australis* in Connecticut, USA. Following herbicide application late in the growing season, the stands of vegetation were then mulched the following spring. This was achieved by hand-cutting or mowing (Farnsworth and Meyerson 1999).

5.9.2.2 Chemical control

Chemicals have been used to control aquatic weeds including *Spartina anglica* in the estuarine/marine environment and *Eichhornia crassipes* and *Myriophyllum aquaticum* in freshwaters with varying success. This includes the herbicides: 2,4-D, dichlobenil, glyphosate (eg. Rodeo®; Monsanto Inc.), gluphosinate, fluazifop-p-butyl (Fusilade®; ICI Americas Inc.), Dalapon, Feneron and diquat (Evans 1986; Daehler and Strong 1996; Eno *et al.* 1997; RGAG 1998; Moreira *et al.* 1999). However, the use of herbicides has major implications for native flora and fauna, human health, aquaculture and recreation and regulations exist in most countries on the use of chemicals in such environments. Another problem with chemical treatment of vegetation is that large masses of dying/decomposing plants can have an ecological impact, particularly on water quality in an environment already stressed from the actual chemicals used (RGAG 1998; Moreira *et al.* 1999).

Research in Victoria found Fusilade® to be the most suitable herbicide for eradication and control of medium to large-scale rice grass infestations with an efficacy as high as 99%. In addition, it does not appear to effect native salt marsh vegetation and seagrass and has little impact on fish and aquatic invertebrates. Fusilade® is generally mixed with a surfactant to enhance performance and is applied using a pressurised backpack sprayer (Rash *et al.* 1995).

The herbicide Rodeo® has glyphosate as its active compound and has been used to control *Spartina alternifolia* in Washington, USA estuaries; mixed with a surfactant the herbicide was aerially applied to mudflats (Simenstad *et al.* 1996). A 1% Rodeo® solution was applied to the reeds *Phragmites australis* using handheld sprayers and low ground pressure amphibious vehicles (Farnsworth and Meyerson 1999). Rodeo® has been found less effective against rice grass than Fusilade® but continues to be used in Washington State.

Recent research on variation among different genets of *Spartina alterniflora* involved application of crude oil and burning with and without oil treatments to determine differences in pollution effects on clones (Smith and Proffitt 1999). Apparently copper sulphate was sprayed on *Spartina* as a control treatment before World War two in the UK but the efficacy is not discussed in Eno *et al.* (1997). Investigations of *Spartina alternifolia* in New Jersey, USA found the plants to have the ability to survive in highly polluted estuaries and that they were relatively tolerant to copper compounds which hence cannot be recommended as a chemical control option (Waddell and Kraus 1990).

5.9.2.3 Long-term control and management

In their native range, *Spartina* spp. have many species of insect and nematode grazers. The potential biological control agents, the leafhopper insects *Prokelisia* spp. from coastal USA are under investigation as they are restricted to *Spartina* and can kill a high proportion of plants and limit seed set (Wu *et al.* 1999). Further research is being undertaken in the USA including Australian specimens of *Spartina* sent to the University of California (Faithful, 2000; Strong and Grevstad 2000).

Biological control of aquatic weeds in freshwaters has included the enhancement of populations of fish such as the common carp, *Cyprinus carpio*, which increase water turbidity and inhibit plant growth through shading, and tilapias, *Oreochromis aureus* and *O. mossambicus* which graze down the vegetation. The grass carp *Ctenopharyngodon idella* had been introduced to at least 47 nations by 1981 as a biocontrol for aquatic plant species (Moreira *et al.* 1999). However, some of these biocontrol fish species have undergone population explosions and excluded native species. Triploid grass carp have now been produced using temperature and pressure shocking to reduce reproductive success of this species and hopefully afford some environmental protection (Courtenay 1993).

5.9.2.4 Summary

Spartina rhizomes and roots grow to a depth of three metres complicating physical eradication. Physical removal is difficult once clumps exceed ~15 cm diameter. Smothering with black plastic or weed matting may take 6 months and is non-selective. Mechanical removal methods (mowers, weed eaters) have had variable success, depending on season, but are suitable for dense monospecific stands of *Spartina*. Steam treatment may be effective, although non-selective. Annual burning may contribute to the next year’s growth. At present, only herbicides provide a cost-effective treatment for areas larger than 1 hectare. There are many different herbicides available, with varying levels of specificity. The leafhopper insects *Prokelisia* spp. are being investigated as potential biological control agents.

5.9.3 Boring isopods and molluscs

Wooden structures in the marine environment are subject to attack by boring isopod crustaceans (Sphaeromatidae and Limnoriidae) and boring shipworm and piddock molluscs (Teredinidae and

Pholadidae). These wood boring species cause considerable economic damage to pylons, wharves, piers, groynes, lock gates, house stilts, aquaculture facilities and other structures. Of the isopods, limnoriids are found from temperate to tropical waters in fully marine environments, while sphaeromatids can tolerate extremely low salinities, but are restricted to sub-tropical and tropical waters. Most of the teredinid species are found in high salinity conditions, however the low salinity tolerant species are especially voracious and difficult to control. Pholads are found largely in tropical and subtropical waters in high salinity conditions. As sphaeromatids and pholads are filter feeders and do not ingest the wood, they are more difficult to control with preservatives as they are not dependent on the wood for nutrition. Approaches to borer control that have proved effective against teredinids (naturally durable timber, CCA- (a solution of copper, chrome or arsenic salts) or creosote-treated timbers and surface coatings on timbers) under certain circumstances are ineffective for limnoriids and sphaeromids (Craag *et al.* 1999). Successful protection of wooden structures usually requires a combination of anti-crustacean and anti-molluscan borer measures.

5.9.3.1 Physical control

Physical barriers such as plastic wraps, tapes or concrete placed around timber pylons extend the service life of the pylon to that of steel and concrete pylons. These barriers kill marine borers, including *Sphaeroma,* by preventing fresh oxygenated water from coming in contact with the pylon (Cookson 1986).

5.9.3.2 Chemical control

Naturally durable timber such as turpentine (*Syncarpia glomulifea*) is one of the most borer-resistant timbers known and is very resistant to teredinids and limnoriids, which appear unable to penetrate sound turpentine heartwood (Cookson 1986). Commercially, conventional vacuum/pressure treatments of softwoods (eg. *Pinus radiata*) or hardwoods (eg. *Eucalyptus* spp.) with either creosote or a solution of copper, chrome or arsenic salts (CCA) or a sequence of the two, provides effective protection from teredinid borers but not from isopod borers.

As *Sphaeroma* bores mainly in the tidal zone it can be controlled by placing a floating collar around the pylon and filling the gap with modified creosote that can float on seawater. The marine borers are killed by the creosote with the rise and fall of the tide. The creosote floating on the water is then recovered and the float removed until the next treatment ~18 months later (Cookson 1986).

Propylene oxide, butylene oxide and butyl isocyanate modification of wood has shown some promise in controlling *Limnoria* but not *Sphaeroma* (which do not ingest wood). Organochlorine insecticides such as dieldrin, lindane, chlordane and endrin, the organophosphate azinphos-ethyl and synthetic pyrethroids appear to provide some protection against *Limnoria* but not *Sphaeroma* (Craag *et al.* 1999). The fungicide chlorothalonil alone or in combination with the insecticide chlorpyrifos has been shown in laboratory tests to provide protection against *Limnoria* (Craag *et al.* 1999 and citations therein). Treatment with pentachlorophenol (PCP) does not prevent attack by *Sphaeroma.*

5.9.3.4 Long-term control and management

The choice of additives combined with conventional treatments for the control of wood borers is determined not only by efficacy data, but also by health and safety, environmental and economic considerations (Craag *et al.* 1999 and citations therein) and further research is required.

5.9.3.5 Summary

Attempts to control boring marine invertebrates have included the use of durable native timbers or chemical treatments of submerged wooden structures. However sphaeromatid isopods are quite resistant to these methods and different suites of chemicals are being investigated as they are developed to hopefully provide a defence against these borers.

6 REFERENCES

Adami, G., Aleffi, F., Barbieri, P., Favretto, A., Predonzani, S. and Reisenhofer, E. (1997). Bivalves and heavy metals in polluted sediments: a chemometric approach. *Water Air and Soil Pollution* **99**: 615–622.

Agatsuma, Y., Matsuyama, K., Nakata, A., Kawai, T. and Nishikawa, N. (1997). Marine algal succession on coralline flats after removal of sea urchins in Suttsu Bay on the Japan Sea coast of Hokkaido, Japan. *Nippon Suisan Gakkaishi* **63**(5): 672–680.

Allen, S.K. Jr., Howe, A., Gallivan, T., Guo, X. and DeBrosse, G. (1999). Genotype and environmental variation in reversion of triploid *Crassostrea gigas* to the heteroploid mosaics state. *Journal of Shellfish Research* **18**(1): 293.

Alpine, A.E. and Cloern, J.E. (1992). Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. *Limnology and Oceanography* **37**: 946–955.

Alvarez, F., Hines, A.H. and Reaka-Kudla, M.L. (1995). The effects of parasitism by the barnacle *Loxothylacus panopaei* (Gissler) (Cirripedia: Rhizocephala) on growth and survival of the host crab *Rhithropanopeus harrisii* (Gould) (Brachyura: Xanthidae). *Journal of Experimental Marine Biology and Ecology* **192**: 221–232.

American Fisheries Society Fisheries Management Chemicals Subcommittee Task Force on Fisheries Chemicals (AFS) (2000). Importance of rotenone as a management tool for fisheries. *Fisheries (American Fisheries Society)* **25**(5): 22–23.

Andrews, D., Whayman, G. and Edgar, G. (1996). Assessment of optimal trapping techniques to control densities of northern Pacific seastars on marine farm leases. *Final Report to the Fisheries Research and Development Corporation, FRDC Grant 95/066*, 57 pp.

Anon. (1997). Profit in carp. *Fish farming international.* **24**(6): 6.

Atkinson, T. (1996). Parasites of Annelids. *Centre for Research on Introduced Marine Pests Unpublished report*. CSIRO Marine Research, Hobart.

Babcock, R.C., Mundy, C.N. and Whitehead, D. (1994). Sperm diffusion models and in situ confirmation of ling distance fertilisation in the free spawning asteroid *Acanthaster planci*. *Biological Bulletin* **186**: 17–28.

Barahona, M.V. and Sanchez-Fortun, S. (1999), Toxicity of carbamates to the brine shrimp *Artemia salina* and the effect of atropine, BW284c51, iso-OMPA and 2-PAM on carbaryl toxicity. *Environmental Pollution* **104**: 469–476.

Barnham, C. (1998a). Carp in Victoria. *Fisheries Notes* **14.** Natural Resources and Environment, Victoria, Australia.7pp. <http://www.nre.vic.gov.au>.

Barnham, C. (1998b). Removing carp from farm dams by poisoning. *Fisheries Notes* **10**, Natural Resources and Environment, Victoria, Australia. 1pp. <http://www.nre.vic.gov.au>.

Barrett-O'Leary, M. (1995). Southern Region Zebra Mussel Newsletter. Louisiana State University, Louisiana Sea Grant. In: *Abstracts from the Sixth International Zebra Mussel and Other Aquatic Nuisance Species Conference*. Dearborn, Michigan, March 1996.

Barthelemy, G. (1991). Mechanical and biological control of the starfish *Asterias rubens* proliferation, in the Bay of Quiberon (southern Brittany, France). pp.22. In: Aquaculture and the Environment, 1991, Aquaculture Europe '91, Dublin (Eire), 10-12 Jun 1991. *Special Publication, European Aquaculture Society*, **14**.

Bax, N.J. (1999). Eradicating a dreissenid from Australia. *Dreissena!* **10**: 1–5.

Bax, N.J. (2000). Marine invaders: Control options. In: *South Africa/United States of America Bi-National Commission on Best Management Practices for Controlling Invasive Alien Species. Cape Town, South Africa, 22–24 February 2000.*

Bax, N., Carlton, J., Mathews-Amos, A., Haedrich, R., Howarth, F.G., Purcell, J, Reiser, A. and Gray, A. (2001). Conserving marine biodiversity: the control of biological invasions in the world’s oceans. *Conservation Biology* **451**: 145-176.

Belanger, S.E., Farris, J.L., Cherry, D.S., and Cairns, J. (1990). Validation of *Corbicula fluminea* growth reductions induced by copper in artificial streams and river systems. *Canadian Journal of Fisheries and Aquatic Science* **47**: 904–914.

Belsher, T. (1991). *Sargassum muticum* (Yendo) Fensholt on the French shoreline: Synthesis of studies, 1983–1989. *IFREMER, Centre de Brest, Del. 91.25*. 96 pp.

Bentler, J. (1998). The effects of mowing *Spartina anglica* during November, December, January and February in Triangle Cove, Camano Island, Washington. In: *Abstracts of technical papers presented at the 51st annual meeting of the Pacific Coast Oyster Growers Association, Newport, Oregon, September 23–25 1997. Journal of Shellfish Research.* **17**(4): 1267.

Berdalet, E. and Estrada, M. (1993). Effects of turbulence on several dinoflagellate species. pp. 737–740. In: Smayda, T.J. and Shimizu, Y. (eds), *Toxic Phytoplankton Blooms in the Sea. Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton. Newport, Rhode Island, USA. 28 October–1 November 1991*. Elsevier Science Publishers, New York, USA.

Berrill, N.J. (1931). Regeneration in *Sabella pavonina* (Sav.) and other sabellid species, *Journal of Experimental Zoology* **58**: 495–523.

Bidwell, J.R., Farris, J.L. and Cherry, D.S. (1995). Comparative response of the zebra mussel, *Dreissena polymorpha*, and the Asian clam *Corbicula fluminea*, to DGH/QUAT, a nonoxidising molluscicide. *Aquatic Toxicology* **33**: 183–200.

Birkeland, C. and Lucas, J.S. (1990). *Acanthaster planci*: major management problem of coral reefs. CRC Press, Boston, Massachusetts, USA. 257 pp.

Blanck, C. A. Mead, D. F. and Adams, D. J. (1996). *Effective Control of Zebra Mussels Using a High Molecular Weight Polymer. The Sixth International Zebra Mussel and Other Aquatic Nuisance Species Conference*. Dearborn, Michigan, March, 1996.

Boelman, S.F., Neilson, F.M., Dardeau, E.A. and Cross, T. (1997). Zebra mussel (*Dreissena polymorpha*) control handbook for facility operators. *Zebra mussel Research Program, Miscellaneous paper EL-97-1*, U.S. Army Corps of Engineers, Washington, DC, USA, 58 pp.

Boghen, A.D., Brun, N.T. and Bataller, E. (1999) The association between the turbellarian *Urastome cyprinae* and the Eastern oyster *Crassostrea virginica*, In: *Abstracts of technical papers presented at the 91st annual meeting of the National Shellfisheries Association, Halifax, Nova Scotia, Canada, April 18–22, 1999. Journal of Shellfish Research* **18**(1): 296.

Bolch, C.J. and Hallegraeff, G.M. (1993). Chemical and physical treatment options to kill toxic dinoflagellate cysts in ships' ballast water. *Journal of Marine Environmental Engineering* **1**: 23–29.

Boles, L.C. and Lipcius, R.N. (1997). Potential for population regulation of the zebra mussel by finfish and the blue crab in North American estuaries. *Journal of Shellfish Research* **16**(1): 179–186.

Boltovskoy, D., Correa, N., Cataldo, D., Stripeikis, J. and Tudino, M. (1997). Environmental stress on *Corbicula fluminea* (Bivalvia) in the Parana River delta (Argentina): complex pollution-related disruption of population structures. *Archiv fur Hydrobiologie* **138**(4): 483–507.

Boogaard, M.A., Bills, T.D., Selgeby, J.H. and Johnson, D.A. (1997). Evaluation of piscicides for control of ruffe. pp.27. In: Jensen, D.A. (ed), *Proceedings of the International Symposium on Biology and Management of Ruffe*, Ann Arbor, Michigan (USA), 21-23 Mar 1997.

Boon, P.I., Bunn, S.E., Green, J.D. and Shiel, R.J. (1994). Consumption of cyanobacteria by freshwater zooplankton: implications for the success of "top-down" control of cyanobacterial blooms in Australia, In: Jones, G.J. (ed.), *Cyanobacterial research in Australia. CSIRO Australia* (Reprinted from: *Australian Journal of Marine and Freshwater Research* **45**(5): 145–157.

Boudouresque, C-F., Ballestros, E., Cinelli, F., Henocque, A., Meinesz, A., Pesando, D., Pietra, F., Ribera, M.A. and Tripaldi, G. (1996). Synthese des resultats du programme CC-Life "Expansion de l'algue verte tropicale *Caulerpa taxifolia* en Mediterranee". pp. 11–57. In: Ribera M.A., Ballestros E., Boudouresque, C-F., Gomez and A., Gravez, V. (eds). *Second International Workshop on Caulerpa taxifolia*. Publications Universitat Barcelona.

Bower, S.M. (1997). *Synopsis of infectious diseases and parasites of commercially exploited shellfish: sabellid polychaete infestation disease in abalone*. <http://www-sci.pac.dfo-mpo.gc.ca/sealane/aquac/pages/sabelab.htm>

Bower, S.M., McGladdery, S.E. and Price, I.M. (1994). *Synopsis of infectious diseases and parasites of commercially exploited shellfish: Sphenophrya-like ciliates of clams and cockles.* <http://www-sci.pac.dfo-mpo.gc.ca/sealane/aquac/pages/spccc/htm>

Bower, S.M. and Meyer, G.R. (1999). Effect of cold water on limiting or exacerbating some oyster diseases, In: *Abstracts of technical papers presented at the 91st annual meeting of the National Shellfisheries Association, Halifax, Nova Scotia, Canada, April 1—-22, 1999. Journal of Shellfish Research* **18**(1): 296.

Boyd, C.E. (1996). Chlorination and water quality in aquaculture ponds. *World Aquaculture* **Sep**:41–45.

Brake, J.W., Davidson, J. and Davis, J. (1999). Triploid production of *Mytilus edulis* in Prince Edward Island – an industrial initiative. In: *Abstracts of technical papers presented at the 91st annual meeting of the National Shellfisheries Association, Halifax, Nova Scotia, Canada, April 18–22, 1999. Journal of Shellfish Research* **18**(1): 302.

Bratbak, G., Wilson, W. and Heldal, M. (1996). Viral control of *Eniliania huxleyi* blooms? *Journal of Marine Systems* **9**: 75–81.

Bricel, V.M., Greene, M. and Cembella, A.D. (1993). Growth of the blue mussel *Mytilus edulis* on toxic *Alexandrium fundyense* and effects of gut passage on dinoflagellate cells. pp.371–376. In: Smayda, T.J. and Shimizu, Y. (eds). *Phytoplankton Blooms in the Sea. Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton. Newport, Rhode Island, USA. 28 October–1 November, 1991*. Elsevier Science Publishers, New York, USA.

Brinkhuis, B.H. and Chung, I.K. (1986). The effects of copper on the fine structure of the kelp *Laminaria saccharina* (L.). *Marine Environmental Research* **19**: 205–223.

Brock, J.A. and Lightner, D.V. (1990). Diseases of Crustacea. Diseases caused by microorganisms. In: Kinne, O. (ed.). *Diseases of Marine Animals. Volume 3.* Biologische Anstalt Helgoland, Hamburg, Germany.

Brooks, K.M., (1993). Impacts on benthic invertebrate communities caused by aerial application of carbaryl to control burrowing shrimp in Willapa Bay, Washington. In: *Abstracts of technical* *papers presented at the 85th annual meeting of the National Shellfisheries Association, Portland, Oregon, May 31–June 3, 1993. Journal of Shellfish Research* **12**(1): 146.

Brown, C.L. and Luoma, S.N. (1995). Use of the euryhaline bivalve *Potamocorbula amurensis* as a biosentinel species to assess trace metal contamination in San Francisco Bay. *Marine Ecology Progress Series* **124**: 129–142.

Bumann, D. and Puls, G. (1996). Infestation with larvae of the sea anemone *Edwardsia lineata* affects nutrition and growth of the ctenophore *Mnemiopsis leidyi*. *Parasitology* **113**: 123–128.

Burridge, T.R. and Gorski, J. (1998). The use of biocidal agents as potential control mechanisms for the exotic kelp, *Undaria pinnatifida*. *Centre for Research on Introduced Marine Pests. Technical Report No.* ***16***. CSIRO Marine Research, Hobart. 27 pp.

Busiahn, T.R. (1996). Ruffe control program, *Report to the Ruffe Control Committee: Aquatic Nuisance Species Task Force.* California Department of Water Resources, Environmental Services Office, Sacremento, California, USA.

<http://midwest.fws.gov/ashland/ruffe/ruf_cont.html>

Calvo-Ugarteburu, G. and McQuaid, C.D. (1998). Parasitism and introduced species: epidemiology of trematodes in the intertidal mussels, *Perna perna* and *Mytilus galloprovincialis*. *Journal of Experimental Biology and Ecology* **220**: 47–65.

Campbell, M.L. (2000). *An empirical evaluation of Posidonia australis (R. Br.) Hook f. restoration in Western Australia: Development of a decision-based restoration framework.* PhD dissertation. Murdoch University, Perth, Australia. 167 pp.

Campbell, M.L. and Hewitt, C.L. (1999). Vectors, shipping and trade. pp.45–60. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E. and Martin, R.B. (eds). *Marine Biological Invasions of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests. Technical Report No.* **20.** CSIRO Marine Research, Hobart.

Campbell, M.L. and Hewitt, C.L. (*in prep*). The discovery and population demography of the introduced dreissenid, *Mytilopsis sallei* Conrad 1857, in Darwin Harbour, Northern Territory.

Campbell, S.J. (1999a). Uptake of ammonium by four species of macroalgae in Port Phillip Bay, Victoria, Australia. *Marine Freshwater Research* **50**: 515–522.

Campbell, S.J. (1999b). Occurrence of *Codium fragile* ssp. *tomentosoides* (Chlorophyta: Bryopsidales) in marine embayments of Southeastern Australia. *Journal of Phycology* **35**: 938–940.

Campbell, S.J. and Burridge, T.R. (1998) Occurrence of *Undaria pinnatifida* (Phaeophyta: Laminariales) in Port Phillip Bay, Victoria, Australia. *Marine and Freshwater Research* **49**: 379–381.

Campello, F. (1991). Troubles d'origines biotiques et abiotiques des macrophytes marins d'interets alimentaire et industriel, *Catalogue 1991*. Institut Francais de Recherche pour L'Exploitation de al Mer, France. 39 pp.

Cantelmo, A., Mantel, L., Lazell, R., Hospod, F., Flynn, E., Goldberg, S. and Katz, M. (1982). The effects of benzene and dimethylnaphthalene on physiological processes in juveniles of the blue crab, *Callinectes sapidus*. pp.349–389. In: Vernberg, W.B., Calabrese, A., Thurnberg, F.P. and Vernberg, F.J. (eds). *Physiological mechanisms of marine pollutant toxicity*. Academic Press, New York, USA.

Carlton J.T. (1992). Introduced marine and estuarine molluscs of North America: an end-of-the-20th-century perspective. *Journal of Shellfish Research* **11**(2): 489–505.

Carlton, J.T. (1999a). Scale and Ecological Consequences of Biological Invasions in the World’s Oceans. pp. 195-212. In: Sandlund, O.T., Schei, P. J., Viken, A. (eds). *Invasive Species and Biodiversity Management*. Kluwer Publishers, Dordrecht.

Carlton, J.T. (1999b). Molluscan invasions in marine and estuarine communities. *Malacologia* **41**(2): 439–454.

Carlton, J.T. and Ruckelshaus, M.H. (1997), Nonindigenous marine invertebrates and algae. pp.187–201. In: Simberloff, D., Schmitz, D.C. and Brown, T.C. (eds). *Strangers in paradise: Impact and management of nonindigenous species in Florida*. Island Press, Washington DC, USA.

Carlton, J.T., Thompson, J.K., Schemel, L.E. and Nichols, F.H. (1990). Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. *Marine Ecology Progress Series* **66**: 81–94.

Caron, D. and Lonsdale, D. (1999a). Microzooplankton-mesozooplankton coupling and its role in the initiation of blooms of *Aureococcus anophagefferens* (Brown Tides). pp 2. In: Branca, B. and O'Donovan, S. (eds). *Brown Tide Research Initiative* **3**. Seagrant New York, New York <www.seagrant.sunysb.edu/pages/publications.htm>

Caron, D. and Lonsdale, D. (1999b). Microzooplankton-mesozooplankton coupling and its role in the initiation of blooms of *Aureococcus anophagefferens* (Brown Tides). pp 5. In: Branca, B., Schlenk, C. and Focazio, P. (eds). *Brown Tide Research Initiative* **4**. Seagrant New York, New York. <www.seagrant.sunysb.edu/pages/publications.htm>

Carpenter, E. J., Peck, B. B. and Anderson, S. J. (1972). Cooling water chlorination and productivity of entrained phytoplankton, *Marine Biology* **16**:37–40.

Carr, E.M. and Dumbauld, B.R. (2000). Progress implementing a plan to monitor and control populations of the European green crab (*Carcinus maenas*) in Washington coastal estuaries. In: *53. Annual Meeting of the Pacific Coast Oyster Growers Association & Natational Shellfisheries Association, Vancouver, WA (USA), Sept. 29–Oct. 1, 1999. Journal of Shellfish Research* **19**(1): 685.

Carr, L. and Dumbauld, B. (1999). 1999 monitoring and control plans for *Carcinus maenas* in Willapa Bay and Grays Harbour, Washington. *Washington Department of Fish and Wildlife Report*, Washington, USA. 9 pp.

Carton, Y. (1967). *Sabelliphilus sarsi* a parasite of *Sabella spallanzanii*. II. Histopathological reactions of experimental transplantations onto other species. *Archives de Zoologie Experimentale et Generale* **108**: 387–411.

Castric-Fey, A., Girard, A. and L'Hardy-Halos, M.T. (1993). The distribution of *Undaria pinnatifida* (Phaeophyceae, Laminariales) on the coast of St. Malo (Brittany, France). *Botanica Marina.* **36**(4): 351–358.

Ceccherelli, G. and Cinelli, F. (1999). The role of vegetative fragmentation in dispersal of the invasive alga *Caulerpa taxifolia* in the Mediterranean. *Marine Ecology Progress Series* **182:** 299–303.

Centre for Disease Control and Prevention (1995). *Morbidity and Mortality Weekly Report* **44**(11): 1995. <http:vm.cfsan.fda.gov/~mow/cholstuf.html>

Chalker-Scott, L. and Scott, J. (1998). Effectiveness of ultraviolet radiation for control of *Dreissena polymorpha*: a four year study. *Dreissena!* **9**(3): 1–5.

Charrin, J.P., Emer, Y.E. and Gravez, V. (1999). Procede industriel de destruction de la *Caulerpa taxifolia* par diffusion d'algicide au contact de l'algue: developpements, evaluations et perspectives. In: *Abstracts of the 4th International workshop on Caulerpa taxifolia in the Mediterranean Sea, February 1999.*

Christensen, A.M. (1970). Feeding biology of the sea star *Astropecten irregularis*. *Ophelia* 8: 1–134.

Christiansen, M.E., Costlow, J.D. and Monroe, R.J. (1978). Effects of the insect growth regulator Dimilin (TH 6040) on larval development of two estuarine crabs. *Marine Biology* **50**: 29–36.

Chu, F.E., Volety, A.K., and Constantin, G. (1996). A comparison of *Crassostrea gigas* and *Crassostrea virginica*: effects of temperature and salinity on susceptibility to the protozoan parasite, *Perkinsus marinus*. *Journal of Shellfish Research* **15**(2): 375–380.

Chung, I.K. and Brinkhuis, B. (1986). Copper effects in early stages of the kelp *Laminaria saccharina*. *Marine Pollution Bulletin* **17**: 213–218.

Cigarria, J., Fernandez, J. and Magadan, L.P. (1998). Feasibility of biological control of algal fouling in intertidal oyster culture using periwinkles. *Journal of Shellfish Research* **17**(4): 1167–1169.

Clapin, G. and Evans, D.R. (1995). The status of the introduced marine fanworm *Sabella spallanzanii* in Western Australia: A preliminary investigation. *Centre for Research on Introduced Marine Pests Technical Report No.* **2.** CSIRO Division of Fisheries, Hobart. 34 pp.

Clapin, G. (1996). *The filtration rate, oxygen consumption and biomass of the introduced polychaete, Sabella spallanzanii Gmelin, within Cockburn Sound*. Bachelor of Science Honours Thesis, Edith Cowan University, WA. 90pp.

Clarkson, N. and Evans, L.V. (1995). Further studies investigating a potential non-leaching biocide using the marine fouling diatom *Amphora coffeaeformis*. *Biofouling* **9**(1): 17–30.

Claudi, R. and Mackie, G.L. (1994). *Practical Manual for Zebra Mussel Monitoring and Control.* Lewis; Boca Raton. 227 pp.

Coglianese, M.P. and Neff, J.M. (1982). Biochemical responses of the blue crab, *Callinectes sapidus*, to pentachlorophenol. pp. 127–143. In: Vernberg, W.B., Calabrese, A., Thurnberg, F.P. and Vernberg, F.J. (eds). *Physiological mechanisms of marine pollutant toxicity*. Academic Press, New York, USA

Cohen, A.N., Carlton, J.T. and Fountain, M.C. (1995). Introduction, dispersal and potential impacts of the green crab *Carcinus maenas* in San Francisco Bay, California. *Marine Biology* **122**: 225–237.

Colwell, R.R., Brayton, P., Herrington, D., Hall, B., Huq, A. and Levine, M.M. (1996). Viable but non-culturable *Vibrio cholerae 01* revert to a culturable state in the human intestine. *World Journal of Microbiology and Biotechnology* **12**: 28–31.

Cookson, L.J. (1986). Marine borers and timber piling options. *CSIRO Division of Chemical and Wood Technology; Research review*, CSIRO, Australia, pp.1–14.

Coquillard, P., Thibaut, T., Hill, D.R.C., Gueugnot, J., Mazel, C. and Coquillard, Y. (2000). Simulation of the mollusc Ascoglossa *Elysia subornata* population dynamics: application to the potential biocontrol of *Caulerpa taxifolia* growth in the Mediterranean Sea. *Ecological Modelling* **135**: 1–16.

Cottalorda, J-M., Robert, P., Charbonnel, E., Dimeet, J., Menager, V., Tillman, M., De Vaugelas, J. and Volto, E. (1996). Eradication de la colonie de *Caulerpa taxifolia* decouverte en 1994 dans les eaux du Parc National de Port-Cros (Var, France). pp. 149–156. In: Ribera M.A., Ballestros E., Boudouresque, C-F., Gomez, A. and Gravez, V. (eds). *Second International Workshop on Caulerpa taxifolia*. Publications Universitat Barcelona.

Coughanowr, C. (1997). State of the Derwent Estuary: a review of environmental quality data to 1997. *Supervising Scientist Report* **129**, Environment Australia, Canberra. 140pp.

Courtenay, W.R. (1993). Biological pollution through fish introductions. pp. 35–62. In: McKnight, B.N. (ed.) *Biological Pollution: The Control and Impact of Invasive Exotic Species*. Indiana Academy of Science, Indianapolis, USA.

Courtenay, W.R. (1997). Nonindigenous fishes. pp. 109–122. In: Simberloff, D., Schmitz, D.C., Brown, T.C. (eds). *Strangers in paradise: impacts and management of nonindigenous species in Florida*. Island Press, Washington DC, USA.

Craag, S.M., Pitman, A.J. and Henderson, S.M. (1999). Developments in the understanding of the biology of marine wood boring crustaceans and in methods of controlling them. *International Biodeterioration and Biodegradation* **43**: 197–205.

Creese, R., Hooker, S., de Luca, S. and Wharton, Y. (1997). Ecology and environmental impact of *Musculista senhousia* (Mollusca: Bivalvia: Mytilidae) in Tamaki Estuary, Auckland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **31**: 225–236.

Crema, R., Castelli, A. and Prevedelli, D. (1991). Long term eutrophication effects on macrofaunal communities in northern Adriatic Sea. *Marine Pollution Bulletin* **22**: 503–508.

CRIMP (2000). *Seastar Round Up*. <http://www.marine.csiro.au/CRIMP/cleanup/cleanup.htm>.

Cristini, A., Anderson, P. and Halpern, T. (1994). Pest control techniques in bivalve aquaculture; the effects of sound on the control of predation by decapod crustaceans on cultured clams. *World Aquaculture* **24**(4): 52–55.

Critchley, A.T., Farnham, W.F. and Morrell, S.L. (1986). An account of the attempted control of an introduced marine alga, *Sargassum muticum*, in southern England. *Biological Conservation* **35**: 313–332.

Crooks, J.A. (1998). Habitat alteration and community-level effects of an exotic mussel, *Musculista senhousia*. *Marine Ecology Progress Series* **162**: 137–152.

Crooks, J.A. and Soulé, M.E. (1999). Lag times in population explosions of invasive species: causes and implications. pp. 103–126. In: Sandlund, O.T., Schei, P. J. and Viken, A. (eds). *Invasive Species and Biodiversity Management*. Kluwer Academic Publishers.

Crosby, A.W. (1986). *Ecological Imperialism. The Biological Expansion of Europe, 900–1900*. Cambridge University Press; Cambridge. 368 pp.

Culver, C.S. and Kuris, A.M. (1999). The sabellid pest of abalone: the first eradication of an established introduced marine bioinvader? pp. 100-101. In: *First National Conference on Marine Bioinvasions January 24–27, 1999*. Massachusetts Institute of Technology, Massachusetts, USA.

Culver, C.S. and Kuris, A.M. (2000). The apparent eradication of a locally established introduced marine pest. *Biological Invasions* **2**: 245–253.

Currie, D.R., McArthur, M.A. and Cohen, B.F. (2000). Reproduction and distribution of the invasive European fanworm *Sabella spallanzanii* in Port Phillip Bay, Victoria, Australia. *Marine Biology* **136**: 64–656.

Daehler C.C. and Strong D.R. (1996) Status, prediction and prevention of introduced cordgrass *Spartina* spp. invasions in Pacific estuaries, USA. *Biological Conservation* **78**: 51–58.

Dahlsten, D.L. and Garcia, R. (1989). *Eradication of Exotic Pests*. Yale University Press, New Haven and London. 296pp.

Dahlsten, D.L., Garcia, R. and Lorraine, H. (1989). Eradication as a pest management tool. pp. 1–15. In: Dahlsten, D.L., Garcia, R. (eds). *Eradication of Exotic Pests*. Yale University Press, New Haven and London.

Davis, H.C. and Hidu, H. (1696). Effects of pesticides on embryonic development of clams and oysters and on survival and growth of the larvae. *Fisheries Bulletin of the Fish and Wildlife Service* **67**: 393–404.

Davis, J.P. (1997). Optimising triploid production techniques and comparative field performance of Mediterranean mussels *Mytilus galloprovincialis* in Puget Sound. In: *Abstracts of technical papers presented at the 89th annual meeting of the National Shellfisheries Association, Fort Walton Beach, Florida, April 20–24, 1997. Journal of Shellfish Research* **16**(1): 311.

Davis, S.A., Catchpole, E.A. and Pech, R.P. (1999). Models for the introgression of a transgene into a wild population within a stochastic environment, with applications to pest control. *Ecological Modelling* **119**: 267–275.

Dawson, V.K., Bills, T.D. and Boogaard, M.A. (1998). Avoidance behaviour in ruffe exposed to selected formulations of piscicides. *Journal of Great Lakes Research.* **24**(2): 343–350.

Debach, P. (1974). *Biological Control by Natural Enemies*. Cambridge University Press, Cambridge. 323 pp.

Delgado, M. (1999). A new "diablillo parasite" in the toxic dinoflagellate *Alexandrium catenella* as a possibility to control harmful algal blooms. *Harmful Algae News* **19**: 1–3. <http://ioc.unesco.org/hab/news.htm>

DePaola, A. (1981). *Vibrio cholerae* in marine foods and environmental waters: a literature review. *Journal of Food Science* **46**: 66–70.

Desmarchelier, P. and Wong, F. (1998). The potential for *Vibrio cholerae* to translocate and establish in Australian waters. *AQIS Ballast Water Research Series No.***10**, Australian Quarantine and Inspection Service, Canberra, Australia. 47 pp.

Devi, V. (1995). Bioaccumulation and metabolic effects of zinc on marine fouling dreissinid bivalve, *Mytilopsis sallei* (Recluz). *Water Air and Soil Pollution* **81**: 295–304.

Dickman, M. and Zhang, F. (1999). Mid-ocean exchange of container vessel ballast water. 2. Effects of vessel type in the transport of diatoms and dinoflagellates from Manzanillo, Mexico, to Hong Kong, China. *Marine Ecology Progress Series* **176**: 253–262.

Doherty, F.G. (1990). The Asiatic clam, *Corbicula* spp., as a biological monitor in freshwater environments. *Environmental monitoring and assessment* **15**: 143–181.

Doherty, F.G. and Cherry, D.S. (1988). Tolerance levels of the Asiatic clam *Corbicula* spp. to lethal levels of toxic stressors - A review. *Environmental Pollution.* **51**: 269–313.

Domart-Coulon, I., Auzoux-Bordenave, S., Doumenc, D. and Khalanski, M. (2000). Cytotoxicity assessment of antibiofouling compounds and by-products in marine bivalve cell cultures. *Toxicology in Vitro* **14**: 245–251.

Donaghay, P.L. and Osborn, T.R. (1997). Toward a theory of biological-physical control of harmful algal bloom dynamics and impacts. *Limnology and Oceanography* **42**(5): 1283–1296.

Doucette, G.J., McGovern, E.R. and Babinchak, J.A. (1999), Algicidal bacteria active against *Gymnodinium breve* (Dinophyceae). I. Bacterial isolation and characterisation of killing activity, *Journal of Phycology* **35**: 1447–1454.

Douglass, T.G. and Jones, I. (1991). Parasites of California spionid polychaetes. *Bulletin of Marine Science* **48**(2): 308–317.

Doyle K. A., Beers P. T. and Wilson D. W. (1996). Quarantine of aquatic animals in Australia. *Revue Scientifique et Technique de l'Office International des Epizooties* **15**(2): 659–673.

Dumas, J.V. and Witman, J.D. (1993). Predation by Herring gulls (*Larus argentatus* Coues) on two rocky intertidal crab species (*Carcinus maenas* (L.) and *Cancer irroratus* Say). *Journal of Experimental Marine Biology and Ecology* **169**: 89–101.

Dumbauld, B.R., Armstrong, D.A. and Skalski, J. (1997). Efficacy of the pesticide Carbaryl for thalassinid shrimp control in Washington State oyster (*Crassostrea gigas*, Thunberg, 1793) aquaculture. *Journal of Shellfish Research* **16**(2): 503–518.

Dumbauld, B.R. and Kauffman, B.E. (1998). The nascent invasion of green crab (*Carcinus maenas*) in Washington State coastal estuaries, In: *Abstracts of technical papers presented at the 51st annual meeting of the Pacific Coast Oyster Growers Association, Newport, Oregon, September 23–2,5 1997. Journal of Shellfish Research* **17**(4): 1269.

Eng-Wilmot, D.L. and Martin, D.F. (1978). Growth response of the marine blue-green alga, *Gomphosphaeria aponona*, to inorganic nutrients and significance to management of Florida red tide. *Microbios* **19**: 167–179.

Eno, N.C. (1996). Non-native marine species in British waters: effects and controls. *Aquatic Conservation: Marine and Freshwater Ecosystems* **6**: 215–228.

Eno, C.N., Clark, R.A. and Sanderson, W.G. (1997). *Non-native marine species in British waters: a review and directory*. Joint Nature Conservation Committee (JNCC), Peterborough. 152pp.

Environment Australia (1998). National profile of chemicals management infrastructure in Australia. <http://www.environment.gov.au/epg/chemicals/profile.html>

Epstein, P.R. (1993). Algal blooms in the spread and persistence of cholera. *BioSystems* **31**: 209–221.

Erard-Le Denn, E., Chretiennot, M-J. and Probert, I. (2000a). First report of parasitism on the toxic dinoflagellate *Alexandrium minutum* Halim. *Estuarine, Coastal and Shelf Science* **50**: 109–113.

Erard-Le Denn, E., Chretiennot-Dinet, M-J. and Probert, I. (2000b). A parasite of *Alexandrium minutum* in French coastal waters, In: *Abstracts of the 9th International Conference on Algal Blooms: Harmful Algal Blooms 2000. Hobart, Tasmania, Australia*, <http://utas.edu.au/docs/plant_science/HAB2000/>

Evans, P.R. (1986). Use of the herbicide 'Dalapon' for control of *Spartina* encroaching on intertidal mudflats: beneficial effects on shorebirds. *Colonial shorebirds.* **9**(2): 171–175.

Faithful, I. (2000). Controlling *Spartina*, new tests with leafhoppers, *Under Control: Pest Plant and Animal Management News* **12**: 5–6.

Farnsworth, E.J. and Meyerson, L.A. (1999). Species composition and inter-annual dynamics of a freshwater tidal plant community following removal of the invasive grass, *Phragmites australis*. *Biological Invasions* **1**(2–3): 115–127.

Feldman, K. L. and Armstrong, D. A. (1995). Controlling populations of burrowing thalassinid shrimp on oyster culture grounds: effects of harvesting and shell configuration on recruitment of young-of-the-year, In: *Abstracts of technical papers presented at Aquaculture '95. Triennial meeting of the American Fisheries Society, World Aquaculture Society and National Shellfisheries Association. Journal of Shellfish Research* **14**(1): 265.

Ferguson, R. (2000). The effectiveness of Australia's response to the black striped mussel incursion in Darwin, Australia. *Report of the Marine Pest Incursion Management Workshop – 27–28 August, 1999.* Department of Environment and Heritage, Canberra, Australia. 77pp.

Fletcher, R.L. and Farrell, P. (1999). Introduced brown algae in the northeast Atlantic, with particular respect to *Undaria pinnatifida* (Harvey) Suringar. *Helgolander Meeresunters* ***52***: 259–275.

Floc'h, J., Pajot, R. and Wallentinus, I. (1988) The Japanese brown alga *Undaria pinnatifida* on the coasts of France and the possibilities of its establishment in European waters. . pp. 1–16. In:

Case histories of the effects of transfers and introductions of marine resources. ICES, Bergen, Norway.

Floc'h, J.Y., Pajot, R. and Wallentinus, I. (1991). The Japanese brown alga *Undaria pinnatifida* on the coast of France and its possible establishment in European waters. *J. Cons. Int. Explor. Mer.* **47**(3): 379–390.

Forrest, B., Taylor, M. and Hay, C. (1997). Foreign Marine Species in New Zealand: Towards a Risk Assessment and Management Model. *Cawthron Report No.* **424**, Cawthron Institute, Nelson, New Zealand.

Frid, C.L.J., Chandrasekara, W.U. and Davey, P. (1999). The restoration of mud flats invaded by common cord-grass (*Spartina anglica*, C.E. Hubbard) using mechanical disturbance and its effects on the macrobenthic fauna. *Aquatic Conservation: Marine and Freshwater Ecosystems* **9**(1): 4–-61.

Furlani, D. (1997). A bibliography of the introduced marine species in Australian waters. *Centre for Research on Introduced Marine Pests Technical Report No.* **12**. CSIRO Marine Research, Hobart. 178 pp.

Furuki, M. and Kobayashi, M. (1993). Interaction between *Chattonella* and bacteria and prevention of this red tide. *Marine Pollution Bulletin* **23**: 189–193.

Gambi, M.C., Castelli, A., Giangrande, A., Lanera, P., Prevedelli, D. and Zunarelli Vandini, R. (1994). Polychaetes of commercial and applied interest in Italy: an overview, In: Dauvin, J-C., Laubier, L. and Reish, D.J. (eds). *Acetes de la 4eme Conference internationale des Polychetes/ Proceedings of the 4th international polychaete conference. Memoires du Museum National d' Histoire Naturelle* **162**: 593–603.

Ganteaume, A., Gobert, J., Malestroit, P., Menager, V., Francour, P. and Boudouresque, C-F. (1998). In vitro consumption of *Caulerpa taxifolia* (Chlorophyta) by accustomed and non-accustomed *Paracentrotus lividus* (Echinoid): Seasonal variations. *Journal of the Marine Biological Association of the United Kingdom* **78**(1): 239–248.

Ganti, S.S. and Kalyanasundaram, N. (1975). A successful method of preventing fouling in seawater conduits by electrolytic chlorine generation. *Bull. Dept. Mar. Sci. Univ. Cochin* **7**(2): 231–234.

Garnham, J. (1998). Distribution and impact of *Asterias amurensis* in Victoria. pp. 18–21. In: Goggin, C.L. (eds). *Proceedings of a meeting on the biology and management of the introduced seastar Asterias amurensis in Australian waters. 19 May 1998. Centre for Research on Introduced Marine Pests. Technical Report No.* **16**. CSIRO Marine Research, Hobart.

Gavach, C., Bonnal, L., Uchimura, M., Sandeaux, R., Sandeaux, J., Souard, R., Combes, J-F., Gravez, V. and Palluy, F. (1999). Developpement pre-industriel de la destrcutyion de *Caulerpa taxifolia* par la technique de la cuverture a ions cuivrique. Resultats des essais. In: *Abstracts of the 4th International workshop on Caulerpa taxifolia in the Mediterranean Sea, February 1999.*

Gavach, C., Sandeaux, R., Sandeaux, J., Souard, R., Uchimura, M. and Escoubet, P. (1996). Technique de destruction de *Caulerpa taxifolia* par emission d'ions cuivrique au moyen d'un panneau a membrane permselective. pp. 139–144. In: Ribera M.A., Ballestros E., Boudouresque, C-F., Gomez, A. and Gravez, V. (eds). *Second International Workshop on Caulerpa taxifolia*. Publications Universitat Barcelona.

Gehrke, P.C. and Harris, J.H. (1994). The role of fish in cyanobacterial blooms in Australia, In: Jones, G.J. (ed.). *Cyanobacterial research in Australia*, CSIRO Australia (Reprinted from *Australian Journal of Marine and Freshwater Research* **45**(5): 175–185.

GESAMP (The Joint Group of Experts on the Scientific Aspects of Marine Environment Protection; IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP) (1997). Opportunistic settlers and the problem of the ctenophore *Mnemiopsis leidyi* invasion in the Black Sea. *GESAMP Reports and Studies* **58.** International Maritime Organisation, London, Great Britain. 84 pp.

Giangrande, A., Licciano, M., Pagliara, P. and Gambi, M.C. (2000). Gametogenesis and larval development in *Sabella spallanzanii* (Polychaeta: Sabellidae) from the Mediterranean Sea. *Marine Biology* **136**: 847–861.

Giangrande, A. and Petraroli, A. (1994). Observations on reproduction and growth of *Sabella spallanzanii* (Polychaeta, Sabellidae) in the Mediterranean Sea. In: Dauvin, J-C., Laubier, L. and Reish, D.J. (eds). *Acetes de la 4eme Conference internationale des Polychetes/ Proceedings of the 4th international polychaete conference*, *Memoires du Museum National d' Histoire Naturelle* **162**: 51–56.

Gibbs, H.N. (1946). The control and utilisation of starfish in Rhode Island waters. *Bulletin of the Bingham Oceanographic Collection* **9**(3): 28–30.

Gnassia-Barelli, M., Romeo, M. and Puiseux-Dao, S. (1995). Effects of cadmium and copper contamination on calcium content of the bivalve *Ruditapes decussatus*. *Marine Environmental Research* **39**: 325–328.

Goggin, C.L. (1997). Parasites (excluding *Sacculina*) which could regulate populations of the European green crab *Carcinus maenas*. pp. 87–91. In: Thresher, R.E. (ed.). *Proceedings of the First International Workshop on the demography, impacts and management of introduced populations of the European crab, Carcinus maenas. Centre for Research on Introduced Marine Pests. Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Goggin, C.L. (1998a). Proceedings of a meeting on the biology and management of the introduced seastar *Asterias amurensis* in Australian waters, 19 May 1998. *Centre for Research on Introduced Marine Pests. Technical Report No.* **15**. CSIRO Marine Research, Hobart. 75 pp.

Goggin, C.L. (1998b). Options for biological control of *Asterias amurensis*. pp. 53–58. In: Goggin, C.L. (ed.). *Proceedings of a meeting on the biology and management of the introduced seastar Asterias amurensis in Australian waters, 19 May 1998. Centre for Research on Introduced Marine Pests. Technical Report No.* **15**. CSIRO Marine Research, Hobart.

Goggin, C.L. (1999). Control of the introduced seastar *Asterias amurensis* in Australian waters. pp. 477–479. In: Candia Carnevali, M.D. and Bonasoro, F. (eds). *Echinoderm Research, 1998. Proceedings of the Fifth European Conference on Echinoderms, Milan, Italy, 7–12 September, 1998*. A.A. Balkema, Rotterdam.

Goggin, C.L. and Bouland, C. (1997). The ciliate *Orchitophrya cf. stellarum* and other parasites and commensals of the Northern Pacific seastar, *Asterias amurensis,* from Japan. *International Journal for Parasitology.* **27**(11): 1415–1418.

Gollasch S., Minchin D., Rosenthal H. and Voigt M. (1999). *Exotics across the ocean: Case histories on introduced species. Report prepared by members of the European Union concerted action on testing monitoring systems for risk assessment of harmful introductions by ships to European waters.* Department of Fishery Biology, Institut for Marine Science, University of Kiel, Germany. 74pp.

Gollasch, S. (1999). Exotics across the ocean – *Eriocheir sinensis* (Milne-Edwards, 1854) (Brachyura, Decapoda). pp. 55–60. In: Gollasch, S., Minchin, D., Rosenthal, H. and Voigt, M. (eds). *Case histories on introduced species: their general biology, distribution, range expansion and impact*. Department of Fishery Biology, Institut for Marine Science, University of Kiel, Germany.

Gomes, V. (1991). First results of tagging experiments on crab *Carcinus maenas* (L.) in Ria de Aveiro Lagoon, Portugal, *Cienc. Biol. Ecol. Syst.* **11**: 21–29.

Gotto, R.V. (1960). Observations on the orientation and feeding of the copepod *Sabelliphilus elongatus* M. Sars on its fanworm host. *Proceedings of the Zoological Society of London* **133**: 619–628.

Graney, R.L., Cherry, D.S. and Cairns, J. (1983). Heavy metal indicator potential of the Asiatic clam (*Corbicula fluminea*) in artificial stream systems. *Hydrobiologia* **102**: 81–88.

Grannum, R.K., Murfet, N.B., Ritz, D.A. and Turner, E. (1996). The distribution and impact of the exotic seastar *Asterias amurensis* (Lutken) in Tasmania. pp. 55-138. In*: The introduced northern Pacific seastar, Asterias amurensis in Tasmania.* Australian Nature Conservation Agency, Canberra.

Grau, A., Pou, S., Riera, F., Pastor, E. and Ballestros, E. (1996). Monitoring of the population of *Caulerpa taxifolia* in Cala D'Or (Mallorca, Western Mediterranean). pp. 131–134. In: Ribera M.A., Ballestros E., Boudouresque, C-F., Gomez, A. and Gravez, V. (eds). *Second International Workshop on Caulerpa taxifolia*. Publications Universitat Barcelona.

Gravez, V., Boudouresque, C-F., Meinesz, A., Cottalorda, J.M. and Roy, D. (1999). Recent advances in the strategy of control of *Caulerpa taxifolia* in the French Mediterranean coasts. In: *Abstracts of the 4th International workshop on Caulerpa taxifolia in the Mediterranean Sea, February 1999.*

Grewe, P. (1996). Review and evaluation of the potential of molecular approaches for the environmentally benign management of the common carp (*Cyprinus carpio*) in Australian waters. *Centre for Research on Introduced Marine Pests. Technical Report No.* **10**. CSIRO Marine Research, Hobart. 22 pp.

Grewe, P. (1997). Molecular approaches for the environmentally benign management of pest species. pp. 95–97. In: Thresher, R.E. (eds). *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced Populations of the European crab, Carcinus maenas. 20–21 March 1997, CSIRO Marine Laboratories, Hobart. Centre for Research on Introduced Marine Pests Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Grosholz, E.D. and Ruiz, G.M. (1995). Does spatial heterogeneity and genetic variation in populations of the xanthid crab *Rhithropanopeus harrisii* (Gould) influence the prevalence of an introduced parasitic castrator? *Journal of Experimental Marine Biology and Ecology* **187**: 129–145.

Gross, E. and Enevoldsen, H. (1998). GEOHAB: Global Ecology and Oceanography of Harmful Algal Blooms. A plan for Co-ordinated Scientific Research and Co-operation to Develop International Capabilities for Assessment, Prediction and Mitigation. *Report from a Joint IOC/SCOR Workshop, Havreholm, Denmark, 13–17 October 1998.* <http://www.jhu.edeu/~scor/GEOHAB.htm>

Gunther, A.J., Davis, J.A., Hardin, D.D., Gold, J., Bell, D., Crick, J.R., Scelfo, G.M., Sericano, J. and Stephenson, M. (1999). Long-term bioaccumulation monitoring with transplanted bivalves in the San Francisco estuary. *Marine Pollution Bulletin* **38**(3): 170–181.

Hall, S.R. and Mills, E.L. (2000). Exotic species in large lakes of the world. *Aquatic Ecosystem Health and Management* **3**: 105–135.

Hallegraeff G. M. (1998). Transport of toxic dinoflagellates via ships' ballast water: Bioeconomic risk assessment and efficacy of possible ballast water management strategies. *Marine Ecology Progress Series* **168**: 297–309.

Hallegraeff G.M. and Bolch C.J. (1992). Transport of diatom and dinoflagellate resting spores in ships' ballast water: implications for plankton biogeography and aquaculture. *Journal of Plankton Research* **14**(8): 1067–1084.

Hallegraeff, G.M., Valentine, J.P., Marshall, J-A. and Bolch, C.J. (1997). Temperature tolerances of toxic dinoflagellate cysts: application to the treatment of ships' ballast water. *Aquatic Ecology* **31**: 47–52.

Hancock, D.A. (1959). The biology and control of the American whelk tingle *Urosalpinx cinerea* (Say) on English oyster beds. *Fisheries Investigations (Series 2)* **22**(10): 1–66.

Hand, R.E., Nell, J.A. and Maguire, G.B. (1998). Studies on triploid oysters in Australia. X. Growth and mortality of diploid and triploid Sydney rock oysters *Saccostrea commercialis* (Iredale and Roughley). *Journal of Shellfish Research* **17**(4): 1115–1127.

Harbison, G.R. (1993) The potential of fishes for the control of gelatinous zooplankton, *ICES Council Meeting Papers*, ICES, Copenhagen, Denmark. 13 pp.

Harbison, G.R. and Volovik, S.P. (1993). Annex I. Methods for the control of populations of the ctenophore *Mnemiopsis leidyi*, in the Black and Azov Seas. pp. 32–44. *FAO Fisheries Report No.* **495**. *General Fisheries Council for the Mediterranean. Report of the Second Technical Consultation on Stock Assessment in the Black Sea*. Food and Agricultural Organisation of the United Nations, Rome, Italy. 125 pp.

Harmelin, J-G. (1996). Des habitats artificiels pour rehabiliter les fonds colonises par *Caulerpa taxifolia* en Mediterranee. pp. 163–169. In: Ribera M.A., Ballestros E., Boudouresque, C-F., Gomez, A. and Gravez, V. (eds). *Second International Workshop on Caulerpa taxifolia*. Publications Universitat Barcelona.

Harrington, D.K., Van Benschoten, J.E., Jensen, J.N., Lewis, D.P. and Neuhauser, E.F. (1997). Combined use of heat and oxidants for controlling adult zebra mussels. *Water Research* **31**(11): 2783–2791.

Harrison, F.L. Knezovich, J.P. and Rice, D.W. (1984). The toxicity of copper to the adult and early life stages of the freshwater clam, *Corbicula manilensis*. *Archives of Environmental Contamination and Toxicology* **13**: 85–92.

Hay, C.H., and Luckens, P.A. (1987). The Asian kelp *Undaria pinnatifida* (Phaeophyta: Laminariales) found in a New Zealand harbour. *New Zealand Journal of Botany* **25**(2): 329–332.

Healy, J.M. and Lamprell, K.L. (1996). The Atlantic Mediterranean bivalve, *Corbula gibba* (Olivi) (Corbulidae: Myoidea) in Port Phillip Bay, Victoria. *Memoirs of the Queensland Museum* **39**: 315–318.

Hengveld, R. (1999). Modelling of the impact of biological invasions. pp. 127–138. In: Sandlund, O.T., Schei, P. J. and Viken, A. (eds). *Invasive Species and Biodiversity Management*. Kluwer Publishers, Dordrecht.

Hewitt, C.L., Campbell, M.L., Thresher, R.E. and Martin, R.B. (1999). *Marine Biological Invasions of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests Technical Report No.* **20**. CSIRO Marine Research, Hobart. 344 pp.

Hines, A.H., Alvarez, F. and Reed, S.A. (1997). Introduced and native populations of a marine parasitic castrator: variation in prevalence of the rhizocephalan *Loxothylacus panopaei* in xanthid crabs. *Bulletin of Marine Science* **61**(2): 197–214.

Hoeg, J.T., Glenner, H. and Werner, M. (1997). The epicaridean parasite *Portunion moenadis* as a biological control agent on *Carcinus maenas*. pp. 85–86. In: Thresher, R.E. (ed.) *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced*

Populations of the European crab, Carcinus maenas. 20–21 March 1997, CSIRO Marine Laboratories, Hobart. Centre for Research on Introduced Marine Pests. Technical Report No. **11**. CSIRO Marine Research, Hobart.

Holliday, J. and Nell, J. (1987). The Pacific Oyster in New South Wales, *AGFACTS - Division of Fisheries*. 4pp.

Hong, Y-K. (1997). Biotechnology and molecular characterisation of useful seaweeds, In: *15th Symposium on Plant Biology. Algae: Diversity, Environment and Human Affairs. 26 September 1997*, Bukyung National University, Korea.

Horlock, J. (1998). *Coastal weed treatments handbook*. Greening Australia, Victoria. 34pp.

ICES (1997). *National Report for France. 2.0 Deliberate Releases. 2.3. Algae.* WGITMO Report, La Tremblade, France. p.33.

Ichikawa, S., Wakao, Y. and Fukuyo, Y. (1993). Hydrogen peroxide as an extermination agent against cysts of red tide and toxic dinoflagellates. pp. 133–138. In: Smayda, T.J. and Shimizu, Y. (eds) *Toxic Phytoplankton Blooms in the Sea. Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton. Newport, Rhode Island, USA. 28 October – 1 November 1991.* Elsevier Science Publishers, New York, USA.

Imai, I. (1997). Algicidal ranges in killer bacteria of direct attack type for marine phytoplankton. *Bulletin of Plankton Society of Japan* **44**(1–2): 3–9.

International Programme on Chemical Safety (IPCS) (1998). <http:www.int/dsa/cicads.htm>.

Ito, H. (1991). Successful HOTAC methods for developing scallop sowing culture in the Nemuro district of East Hokkaido, Northern Japan. pp. 107–116. In: Svrjeek, R.S. (ed.). *Marine ranching: proceedings of the seventeenth US-Japan meeting on aquaculture, Ise, Mie Prefecture, Japan, October 16–18, 1988. NOAA Technical Report* NMFS **102**.

Janardhana Rao, M., Vijaya Lakshimi, G., Ravi Varma, T., Nageswara Rao, V. and Subba Rao, B.V.S.S.R. (1988) Effect of endosulfan on cardiac activity of *Mytilopsis sallei*. *Biol. Bull. India* **10**(1): 1–4.

Jeffs, A.G., Holland, R.C., Hooker, S.H. and Hayden, B.J. (1999). Overview and bibliography on the greenshell mussel, *Perna canaliculus*, from New Zealand waters. *Journal of Shellfish Research* **18**(2): 347–360.

Jenner, H.A. (1983). Control of mussel fouling in the Netherlands: Experimental and existing methods. pp. 407–421. In: Diaz-Tous, I.A. (ed.). *Symposium on Conderser, Macrofouling Control Technologies- The State of the Art. June 1983*, N.V. Tot Keuring Van Electrotechnische Materialen Arnhem, Hyannis, Massachusetts, USA 18(25–26).

Jenner, H. A., Taylore, C. J. L., van Donk, M. and Khalanski, M. (1997). Chlorination by-products in chlorinated cooling water of some European coastal power stations. *Marine Environmental Research* **43**(4): 279–293.

Jenner, H.A. and Janssen-Mommen, J.P.M. (1993). Monitoring and control of *Dreissena polymorpha* and other macrofouling bivalves in the Netherlands. pp. 537–554. In: Nalepa, T.F. and Schloesser, D.W. (eds). *Zebra mussels: Biology, Impacts and Control*. Lewis Publishers, USA

Jensen, J.N. (1988). Recruitment, growth and mortality of juvenile *Corbula gibba* and *Abra alba* in the Limfjord, Denmark. pp. 357–365. In: *Meeting on the Baltic Sea Environment: History, Eutrophication, Recruitment, Ecotoxicology held at the 10th Symposium of the Baltic Marine Biologists.* Vol. **6**. Kiel Meeresforsch Sonderh.

Jensen, J.N. (1990). Increased abundance and growth of the suspension feeding bivalve *Corbula gibba* in a shallow part of the eutrophic Limfjord, Denmark. *Netherlands Journal of Sea Research* **27**: 101–108.

Jeong, H.J. and Latz, M.I. (1994). Growth and grazing rates of the heterotrophic dinoflagellates *Protoperidinium* spp. on red tide dinoflagellates. *Marine Ecology Progress Series* **106**: 173–185.

Johns, D.M. and Miller, D.C. (1982). The use of bioenergetics to investigate the mechanisms of pollutant toxicity in crustacean larvae. pp. 261–288. In: Vernberg, W.B., Calabrese, A., Thurnberg, F.P. and Vernberg, F.J. (eds). *Physiological mechanisms of marine pollutant toxicity*. Academic Press, New York, USA.

Johnson, S.R. and Knapp, A.K. (1993). The effect of fire on gas exchange and aboveground biomass production in annually vs biennially burned *Spartina pectinata* wetlands. *Wetlands* **13**(4): 299–303.

Karande, A.A. and Menon, K.B. (1975) *Mytilopsis sallei*, a fresh immigrant in Indian harbours. *Bull. Dept. Mar. Sci. Univ. Cochin* **7**(2): 455–466.

Karande, A.A., Gaonkar, S.N., Viswanathan, R. and Sriraman, A.K. (1982). Bioassay of antifoulant chlorine. *Indian Journal of Marine Sciences* **11**: 177–179.

Karande, A.A., Ganti, S.S. and Udhyakumar, M. (1993). Toxicity of tributyltin to some bivalve species. *Indian Journal of Marine Sciences* **22**(2): 153–154.

Kardon, G. (1998). Evidence from the fossil record of an antipredatory adaptation: concholin layers in corbulid bivalves. *Evolution* **52**(1): 68–79.

Kelleher, B., Van der Velde, G., Giller, P.S. and de Vaate, A.B. (2000). Dominant role of exotic invertebrates, mainly Crustacea, in diets of fish in the lower Rhine River. pp. 35-46. In: Von Vaupel Klein, J.C. and Schram, F.R. (eds). *Crustacean issues 12: The biodiversity crisis and Crustacea. Proceedings of the fourth international Crustacea congress, Netherlands, 20–24 July 1998. Volume* **2**. A. A. Balkema, Rotterdam.

Kim, H.R., Kim, K.I., Kim, D.S., Park, K.S., Hong, T.H. and Jeong, H.J. (2000). Developing a methods of controlling the outbreak and maintenance of red tides using NaOCl produced by electrolysis of natural seawater. In: *Abstracts of the 9th International Conference on Algal Blooms: Harmful Algal Blooms 2000. Hobart, Tasmania, Australia*, <http://www.utas.edu.au/plant_science/HAB2000>.

Kimor, B. (2000). From the history of toxic algal blooms in Israel. The case of *Prymnesium parvum* and its control. In: *Abstracts of the 9th International Conference on Algal Blooms: Harmful Algal Blooms 2000. Hobart, Tasmania, Australia*.

<http://www.utas.edu.au/plant_science/HAB2000>.

Kimura, T., Ezura, Y. and Tajima, K. (1976). Microbiological study of a disease of Wakame (*Undaria pinnatifida*) and the marine environments of Wakame culture sites in Kesennuma Bay. *Bulletin of the Tohoku Regional Fisheries Research Laboratory* **36**: 57–65.

Kimura, T. and Sekiguchi, H. (1996). Effects of temperature on larval development of two mytilid species and their implication. *Venus: The Japanese Journal of Malacology* **55**(3): 215–222.

Kiortsis, V. and Moraitou, M. (1965). Factors of regeneration in *Spirographis spallanzanii*. pp. 250–261. In: Kiortsis, V. (eds). *Regeneration of animals and related problems*. North Holland Publishing Company, Amsterdam.

Kitto, H., Akiyama and K., Sasaki, L. (1976). Electron microscopic observations on the diseased thalli of *Undaria pinnatifida* (Harvey) Suringar, caused by parasitic bacteria. *Bulletin of the Tohoku Regional Fisheries Research Laboratory* **36**: 67–73.

Kochina, E.M. (1999). First mass record of *Beroe ovata* in Calamitsky Bay of the Black Sea. *Vestnik zoologii, Kiev* **33**(6): 26.

Kozloff, E.N. (1961). A new genus and two new species of ancistrocomid ciliates (Holotricha: Thigmotrica) from sabellid polychaetes and from a chiton. *Journal of Protozoology* **8**(1): 60–63.

Kozloff, E.N. (1965). *Ciliocincta sabellariae* g. and sp. n., an orthonectid mesozoan from the polychaete *Sabellaria cementarium* Moore. *Journal of Parasitology* **51**(1): 37–44.

Kreps, T.A., Purcell, J.E. and Heidelberg, K.B. (1997). Escape of the ctenophore *Mnemiopsis leidyi* from the scyphomedusa predator *Chrysaora quinquecirrha*. *Marine Biology* **128**: 441–446.

Kriwoken, L.K. and Hedge, P. (2000). Exotic species and estuaries: managing *Spartina anglica* in Tasmania, Australia. *Ocean and Coastal Management* **43**: 573–584.

Kumate, J., Spulveda, J. and Gutierrez, G. (1998) Cholera epidemiology in Latin America and perspectives for eradication. *Bull, Inst. Pasteur* **96**: 217–226.

Kuris, A. (1997). Nemertean egg predators as potential biocontrol agents for *Carcinus maenas*. pp. 82–84. In: Thresher, R.E. (ed.). *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced Populations of the European crab, Carcinus maenas. 20–21 March 1997, CSIRO Marine Laboratories, Hobart, Centre for Research on Introduced Marine Pests Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Kuris, A. and Gurney, R. (1997). Survey of Tasmanian crabs for parasites: A progress report. pp. 92–94. In: Thresher, R.E. (eds). *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced Populations of the European crab, Carcinus maenas. 20-21 March 1997, CSIRO Marine Laboratories, Hobart, Centre for Research on Introduced Marine Pests. Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Kutt, E.C. and Martin, D.F. (1975). Report on a biochemical red tide repressive agent. *Environmental Letters* **9**: 195–208.

Laabir, M. and Gentien, P. (1999). Survival of toxic dinoflagellates after gut passage in the Pacific oyster *Crassostrea gigas* Thunberg. *Journal of Shellfish Research* **18**(1): 217–222.

Lafferty, K. D. and Kuris, A. M. (1996), Biological control of marine pests. *Ecology* **77**(7): 1989–2000.

Lawrence, E. (1992). *Henderson's Dictionary of Biological Terms, 10th Edition.* Longman Scientific and Technical, Singapore. 645pp.

Lee, C.F. (1948). Technological studies of the starfish. Part 1. Starfish control- its economic necessity and methods used. *Commercial Fisheries Review* **10**(1): 1–6.

Leigh, P. (1998). Benefits and costs of the *Ruffe* control program for the Great Lakes fishery. *Journal of Great Lakes Research* **24**(2): 351–360.

Leighton, D.L. (1998). Control of sabellid infestation in green and pink abalones, *Haliotis fulgens* and *H. corrufata* by exposure to elevated water temperatures. *Journal of Shellfish Research* **17**(3): 701–705.

Lemma, A., Wolde-Yohannes, L., Fraleigh, P.C., Klerks, P.L. and Lee, H.H. (1991). Endod is lethal to zebra mussels and inhibits their attachment. *Journal of Shellfish Research* **10**(2): 361–365.

Les, D.H. and Mehrhoff, L.J. (1999). Introduction of nonindigenous aquatic vascular plants in southern New England: a historical perspective. *Biological Invasions* **1**: 281–300.

Levitan, D.R. and Sewell, M.A. (1998). Fertilisation success in free-spawning marine invertebrates: review of the evidence and fisheries implications. In: Jamieson, G.S., Campbell, A. (eds).

Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Canadian Fisheries and Aquatic Science; Special Publication **125:** 159–164.

Lewis, B.G. (1985). Mussel control and chlorination. *Report No. TPRD/L/2810/R85.* Central Electricity Research Laboratories, Leatherhead, Surrey, UK. 33pp.

Lewis, D. and Pawson, R.L. (1993). Use of cathodic protection as a means of control and removal of Zebra Mussels. In: *Third International Zebra Mussel Conference*, *Agenda and Abstracts*. Toronto, Canada.

Lewis, J.A. (1999). A review of the occurrence of exotic macroalgae in southern Australia, with emphasis on Port Phillip Bay, Victoria. pp. 61–87. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E. and Martin, R.B. (eds). *Marine Biological Invasions of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests Technical Report No.* **20**. CSIRO Marine Research, Hobart.

Line, M.A. (1994). Composting of seastar (*Asterias amurensis*) wastes. *Report to the National Seastar Task Force.* 9 pp.

Ling, S.D. (2000). *Anthropogenic structure and reproduction of Asterias amurensis*. Bachelor of Science, Honours Thesis, University of Tasmania, Hobart. 66pp.

Lipton, D.W., Lavan, E. F. and Strand, I.E. (1992). Economics of molluscan introductions and transfers: The Chesapeake Bay dilemma. *Journal of Shellfish Research* **11**: 511–519.

Loosanoff, V.L. and Engle, J.B. (1942). Use of lime in controlling starfish. *US Fisheries Wildlife Research Report No.* **2**, US Fisheries and Wildlife Service, USA. 29pp.

Loubser, N.C. and Dormehl, N. (2000). The use of ultrasound in the treatment of sabellid infestations in South African abalone. pp.34–35. In: *4th International Abalone Symposium – Biology, Culture, Fisheries. Abstracts*. University of Cape Town, Cape Town, South Africa.

Lovejoy, C., Bowman, J. P. and Hallegraeff, G. F. (1998). Algicidal effects of a novel marine *Pseudoalteromonas isolate* (Class Proteobacteria, Gamma Subdivision) on harmful algal bloom species of the genera *Chattonella, Gymnodinium* and *Heterosigma. Applied and Environmental Microbiology* **64**(8): 2806–2813.

Lüning, K. (1980). Critical levels of light and temperature regulating the gametogenesis of three *Laminaria*- species (Phaeophyceae). *Journal of Phycology* **16**(1): 1–15.

MacNair, N. and Smith, M. (1999). Investigations into treatments to control fouling organisms affecting oyster production. *Journal of Shellfish Research* **18:** 331.

Maier, I. (1993). Gamete orientation and induction of gametogenesis by pheromones in algae and plants. *Plant, Cell and Environment* **16**: 891–907.

Marsh, S.E. (1993). The biology and distribution of the introduced seastar *Asterias amurensis* (Lutken) (Echinodermata: Asteroidea) in Tasmania, Bachelor of Science Honours Thesis, University of Tasmania, Hobart. 65pp.

Marshall, D. (1999). Pulse generator for biofouling prevention. pp. 422. In: Pederson, J. (ed), *Marine Bioinvasions: Proceedings of the First National Conference, January 24–27, 1999.* Massachusetts Institute of Technology, Massachusetts, USA.

Martin, D.F. and Taft, W.H. (1998). Management of the Florida red tide-revisited. *Florida Scientist* **61**(1): 10–16.

Martin, R.B. (1998). Control of seastars by physical removal. pp. 44–46. In: Goggin, C.L. (ed.). *Proceedings of a meeting on the biology and management of the introduced seastar Asterias amurensis in Australian waters, 19 May 1998. Centre for Research on Introduced Marine Pests. Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Martin, R.B. and Proctor, C. (2000). Tasmanian Marine Pest Marine Farm Monitoring Project. *Final Report for NHT/C&CS Project: IMP16/97.* Centre for Research on Introduced Marine Pests, Hobart. 23 pp.

Marvin, K.T. and Proctor, P.R. (1964). Preliminary results of the systematic screening of 4306 compounds as red tide toxicants. *Data Report* **2,** *U.S. Fisheries and Wildlife Service*.

Matsuoka, K., Cho, H-J. and Jacobson, D.M. (2000). Observations on the feeding behaviour and growth rates of the heterotrophic dinoflagellate *Polykrikos kofoidii* (Polykrikaceae, Dinophyceae). *Phycologia* **39**(1): 82–86.

Matveev, V., Matveeva, L. and Jones, G.J. (1994). Study of the ability of *Daphinia carinata* King to control phytoplankton and resist cyanobacterial toxicity: implications for biomanipulation in Australia. In: Jones, G.J. (ed.). *Cyanobacterial research in Australia*. CSIRO Australia (Reprinted from *Australia Journal of Marine and Freshwater Research* **45**(5): 159–174.

McCarthy S. A. and Khambaty F. M. (1994). International dissemination of epidemic *Vibrio cholerae* by cargo ship ballast and other nonpotable waters. *Applied and Environmental Microbiology* **60**(7): 2597–2601.

McClay, W. (2000). Rotenone use in North America (1988–1997) *Fisheries (American Fisheries Society)* **25**(5): 15–21.

McLoughlin, R. and Bax, N. (1993*). Scientific discussions in Japan and Russia on the northern Pacific seastar.* CSIRO Division of Fisheries, Hobart. 30pp.

McMahon, R.F., Ussery, T.A. and Clarke, M. (1993). Use of emersion as a zebra mussel control method. *Zebra Mussel Research Program. Contract Report El-93-1*, U.S. Army Corps of Engineers, Washington, D.C. 27 pp.

Mearns, A.J. (1996). Exxon Valdez, shoreline treatment and operations: implications for response, assessment, monitoring, and research. pp. 309–328. In: Rice, S.D., Spies, R.B., Wolfe, D.A., Wright, B.A. (eds). *Proceedings of the Exxon Valdez oil spill symposium*, American Fisheries Society, Maryland, USA.

Meinesz, A., (translated by Simberloff, D.) (1999). *Killer algae*. The University of Chicago Press, Chicago, USA. 360pp.

Meinesz, A., Melnyk, J., Blachier, J. and Charrier, S. (1996). Etude preliminaire, en aquarium, de deux ascoglossans tropicaux consommant *Caulerpa taxifolia*: une voie de recherche pour la lutte biologique. pp. 157–162. In: Ribera M.A., Ballestros E., Boudouresque, C-F., Gomez, A. and Gravez, V. (eds). *Second International Workshop on Caulerpa taxifolia*. Publications Universitat Barcelona.

Meronek, T.G., Bouchard, P.M., Buckner, E.R., Burri, T.M., Demmerly, K.K., Hatleli, DoC., Klumb, R.A., Schmidt, S.H. and Coble, D.W. (1996). A review of fish control projects. *North American Journal of Fisheries Management* **16**(1): 63–74.

Milligan, K.L.D. and Cosper, E.M. (1994). Isolation of virus capable of lysing the brown tide alga *Aureococcus anophagefferons*. *Science* **266**: 805–807.

Minchin, D. (1997). The influence of the parasitic cirripede *Sacculina carcini* on its brachyuran host *Carcinus maenas* within its home range. pp. 76–80. In: Thresher, R.E. (ed.). *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced Populations of the European crab, Carcinus maenas. 20–21 March 1997, CSIRO Marine Laboratories, Hobart. Centre for Research on Introduced Marine Pests Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Minchin, D., Duggan, C.B., Holmes, J.M.C. and Neiland, S. (1993). Introductions of exotic species associated with Pacific oyster transfers from France to Ireland, Council Meeting of the International Council for the Exploration of the Sea, [Dublin (Eire)], [23 Sep - 1 Oct 1993] *ICES Council Meeting Papers*, ICES, Copenhagen (Denmark). 11pp.

Miyazaki, T., Kurata, K., Miyazaki, T. and Adachi, R. (1990). Toxic effects of hydrogen peroxide on *Gymnodinium nagasakiense* and fishes. *Bulletin of the Faculty of Bioresources, Mie University* **4**: 165–173.

Molloy, D.P. (1998). The potential for using biological control technologies in the management of *Dreissena* spp. *Journal of Shellfish Research* **17**(1): 177–183.

Montani, S., Mekusumpun, S. and Ichimi, K. (1995). Chemical and physical treatments for destruction of phytoflagellate cysts. *Journal of Marine Biotechnology* **2**(4): 179–181.

Moreira, I., Ferreira, T., Monteiro, A., Catarino, L. and Vasconcelos, T. (1999). Aquatic weeds and their management in Portugal: insights and the international context. *Hydrobiologia.* **415**: 229–234.

Morgan, G., Wright, R., Dawson, A., Bissing, D., Crawford, D., Barrcato, J. and Coogan, J. (1999). UV disinfection of ballast waters: effects of organism size on system scaling. pp. 337. In: Pederson, J. (ed), *Marine Bioinvasions: Proceedings of the First National Conference, January 24–27, 1999.* Massachusetts Institute of Technology, Massachusetts, USA.

Morrice, M.G. (1995). The distribution and ecology of the introduced northern Pacific seastar, *Asterias amurensis* (Lütken), in Tasmania. pp. 1-50. In*: The introduced northern Pacific seastar, Asterias amurensis in Tasmania.* Australian Nature Conservation Agency, Canberra.

Morris, A.E. (2001). Early life history of the introduced seastar Asterias amurensis in the Derwent Estuary, Tasmania: The potential for ecology-based management. PhD dissertation. University of Tasmania, Hobart, Australia. 115 pp.

Morton, B. (1974). Some aspects of the biology, population dynamics, and functional morphology of *Musculista senhousia* Benson (Bivalvia, Mytilidae). *Pacific Science* **28**: 19–33.

Morton, B. (1977). Freshwater fouling bivalves. pp. 1–14. In: Morton, B., Britton, J.C., Mattice, J.S., Murphy, C.E., and Newland, L.W. (eds). *Proceedings of the First International Corbicula Symposium, held at Texas Christian University, Fort Worth, Texas, October 13–15, 1977.* Texas Christian University, Texas, USA.

Morton, B. (1996). The subsidiary impacts of dredging (and trawling) on a subtidal benthic molluscan community in the southern waters of Hong Kong. *Marine Pollution Bulletin* **32**(10): 701–710.

Morton, B.S., Au, C.S. and Lam, W.W. (1976). Control of *Limnoperna fortunei*. *Journal of the Institution of Water Engineers, Scientists* **30**: 144–156.

Mountfort, D.O, Atkinson, M., Ponikla, K., Burke, B. and Todd, K. (1996). Lysis of *Gymnodinium* species by the fungus *Verticillium lecanii*. *Botanica Marina* **39**: 159–165.

Mountfort, D.O., Hay, C., Taylor, M., Buchanan, S. and Gibbs, W. (1999a). Heat treatment of ship's ballast water: development and application of a model based on laboratory studies. *Journal of Marine Environmental Engineering* **5**: 193-206.

Mountfort, D.O., Hay, C. Dodgshun, T, Buchanan, S. and Gibbs, W. (1999b). Oxygen deprivation as a treatment for ships' ballast water- laboratory studies and evaluation. *Journal of Marine Environmental Engineering* **5**: 175-192.

Moy, P.B. (1999). Development of an aquatic nuisance species barrier in a commercial waterway. pp. 357. In: Pederson, J. (ed), *Marine Bioinvasions: Proceedings of the First National Conference, January 24–27, 1999.* Massachusetts Institute of Technology, Massachusetts, USA.

Moyle, P.B. (1999). Effects of invading species on freshwater and estuarine ecosystems. pp. 177–194. In: Sandlund, O.T., Schei, P. J. and Viken, A. (eds). *Invasive Species and Biodiversity Management*. Kluwer Academic Publishers.

Mueller, K.W. and Hoffman, A. (1999). Effect of freshwater immersion on attachment of the Japanese oyster drill, *Ceratostoma inornatum* (Recluz 1851). *Journal of Shellfish Research* **18**(2): 597–600.

Murphy, N. (1999). Asteroid physiology and possible control options for *Asterias amurensis*. *Centre for Research on Introduced Marine Pests Unpublished report*. CSIRO Marine Research, Hobart, 14 pp.

Murphy, N.E. and Goggin, C.L. (2000). Genetic discrimination of Sacculinid parasites (Cirripedia, Rhizocephala): Implication for control of introduced green crabs (*Carcinus maenas*). *Journal of Crustacean Biology* **20**(1): 153–157.

Nagasaki, K., Ando, M., Imai, I., Itakura, S. and Ishida, Y. (1994). Virus-like particles in *Heterosigma akashiwo* (Raphidophyceae): a possible red tide disintegration mechanism. *Marine Biology* **119**: 307–312.

Nel, R., Coetzee, P.S. and Vanniekerk, G. (1996). The evaluation of two treatments to reduce mud worm *(Polydora hoplura claparede)* infestation in commercially reared oysters (*Crassostrea gigas* Thunberg). *Aquaculture* **141**: 31–39.

Noren, F., Moestrup, O. and Rehnstam-Holm, A-S. (2000). *Parvilucifera infectans* (Noren and Moestrup, 1999): a parasitic flagellate capable of killing toxic microalgae, In: *Abstracts of the 9th International Conference on Algal Blooms: Harmful Algal Blooms 2000. Hobart, Tasmania, Australia*. <http://www.utas.edu.au/plant_science/HAB2000>.

NRA Media Release 00/7 (June 2000). *NRA Gets Tough on Endosulfan to Protect Australian Beef.* <http://www.dpie.gov.au/nra/mr0007.html>

NRA Media Release 99/10 (August 1999). *Australian experts to review an UK organophosphate pesticides report.* <http://www.dpie.gov.au/nra/sheepoppr.html>

Oakes, F.R. and Fields, R.C. (1996). Infestation of *Haliotis rufescens* shells by a sabellid polychaete, *Aquaculture* **140**: 139–143.

Oakes, R., Fields, R.C., Arthur, P.F. and Trevelyan, G.A. (1995). The use of wax to control the shell parasites of the red abalone *Haliotis rufescens*. In: *Abstracts of technical papers presented at Aquaculture '95. Triennial meeting of the American Fisheries Society, World Aquaculture Society and National Shellfisheries Association*. *Journal of Shellfish Research* **14**(1): 273.

Oemcke, D. (1999). The treatment of ships' ballast water. *Ecoports Monograph Series* No. **18**, Ports Corporation of Queensland, Brisbane, Queensland. 102 pp.

Panning, A. (1938). The Chinese mitten crab. *Annual Report of the Smithsonian Institute.* pp.361–375.

Parry, G.D., Cohen, B.F., McArthur, M.A. and Hickman, N.J. (2000). Victorian incursion management report number 2. *Asterias amurensis* incursion in Port Phillip Bay: Status at May 1999. *Marine and Freshwater Resources Institute Report No.* **19**, Marine and Freshwater Resources Institute, Queenscliff, Victoria. 21 pp.

Paul, L.J. (1966) Observations of past and present distributions of mollusc beds in Ohiwa Harbour, Bay of Plenty. *New Zealand Journal of Science* **9**: 30–40.

Paula, E.J. and Eston, V.R. (1987). Are there other *Sargassum* species potentially as invasive as *S. muticum*? *Botanica Marina* **30**(5): 405–410.

Pearson, T.H. and Rosenberg, R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology. An Annual Review* **16**: 229–311.

Pereira, W. E., Hostettler, F. D. and Rapp, J. B. (1992). Bioaccumulation of hydrocarbons derived from terrestrial and anthropogenic sources in the Asian clam *Potamocorbula amurensis* in San Francisco Bay estuary. *Marine Pollution Bulletin* **24**: 103–109.

Pereira W.E., Wade, T.L., Hostettler, F.D. and Parchaso, F. (1999). Accumulation of butyltins in sediments and lipid tissues of the Asian clam *Potamocorbula amurensis*, near Mare Island naval shipyard, San Francisco Bay. *Marine Pollution Bulletin* **38**(11): 1005–1010.

Perez, E., Sawyers, W.G. and Martin, D.F. (1997) Identification of allelopathic substances produced by *Nannochloris occulata* that affect a red tide organism, *Gymnodinium breve*. *Biomedical Letters* **56**: 7–14.

Perrett, S. and Whitfield, P.J. (1996). Currently available molluscicides. *Parasitology Today* **12**(4): 156–159.

Peters, A.F. and Burkhardt, E. (1998). Systematic position of the kelp endophyte *Laminarionema elsbetiae* (Ectocarpales *sensu lato*, Phaeophyceae) inferred from nuclear ribosomal DNA sequences. *Phycologia* **37**: 114–120.

Peters, A.F. and Schaffelke, B. (1996). *Streblonema* (Ectocarpales, Phaeophyceae) infection in the kelp *Laminaria saccharina* (Laminariales, Phaeophyceae) in the western Baltic. *Hydrobiologia* **326/327**: 111–116.

Pimental, D., Lach, L., Zuniga, R. and Morrison, D. (2000). Environmental and economic costs of non-indigenous species in the United States. *Bioscience* **50**(1): 53–65.

Pitcairn, M.J. and Manweiler, S.A. (1989). Whitefringed beetle. pp.108-127.In: Dahlsten, D.L. and Garcia, R. (eds). *Eradication of Exotic Pests*. Yale University Press, New Haven and London.

Pitts, J.L. (1993), An integrated pest management plan for the control of burrowing shrimp populations on oyster beds in southwestern Washington State. In: *Abstracts of technical papers presented at the 85th annual meeting of the National Shellfisheries Association, Portland, Oregon, May 31–June 3 1993*. *Journal of Shellfish Research* **12**(1): 147.

Pollard, D.A. and Hutchings, P.A. (1990a). A review of exotic marine organisms introduced to the Australian region. I. Fishes. *Asian Fisheries Science* **3**(303): 205–221.

Pollard, D.A. and Hutchings, P.A. (1990b). A review of exotic marine organisms introduced into the Australian region. II. Invertebrates and algae. *Asian Fisheries Science* **3**: 223–250.

Primary Industries and Resources South Australia (PIRSA) (1999). Green lipped mussels in South Australian Waters, Information pamphlet. *Coast and Clean seas/ NHT, Government of South Australia*, South Australia. 2pp.

Proctor, C. (1997). Possible impacts of *C. maenas* on Tasmanian mariculture and fisheries. pp. 58–59. In: Thresher, R.E. (ed.). *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced Populations of the European crab, Carcinus maenas. 20–21 March 1997, CSIRO Marine Laboratories, Hobart*. *Centre for Research on Introduced Marine Pests. Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Proctor, C. and Thresher, R.E. (1997). The invasive history, distribution and abundance of *C. maenas* in Australia. pp. 31–33. In: Thresher, R.E. (ed.). *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced Populations of the European crab, Carcinus maenas. 20-21 March 1997, CSIRO Marine Laboratories, Hobart.*

Centre for Research on Introduced Marine Pests. Technical Report No. **11**. CSIRO Marine Research, Hobart.

Purcell, J.E. and Cowan, J.H. (1995). Predation by the scyphomedusan *Chrysaora quinquecirrha* on *Mnemiopsis leidyi* ctenophores. *Marine Ecology Progress Series* **129**: 63–70.

Purcell, J.E., Shiganova, T.A., Decker, M.B. and Houde, E.D. (in press). The ctenophore *Mnemiopsis leidyi* in native and exotic habitats: U.S. estuaries vs. the Black Sea basin. *Hydrobiologia*.

Raftos, D.A. and Cooper, E.L. (1990). Diseases of Annelida. pp. 229–243. In: Kinne, O. (ed.). *Diseases of Marine Animals. Volume **2***, Biologische Anstalt Helgoland, Hamburg.

Rajagopal, S., Nair, K. V. K., Azariah, J., van der Velde, G. and Jenner, H. A. (1996). Chlorination and mussel control in the cooling conduits of a tropical coastal power station. *Marine Environmental Research* **41**(2): 201–221.

Rajagopal, S., Nair, K.V.K., van der Velde, G. and Jenner, H.A. (1997a). Response of mussel *Brachidontes striatulus* to chlorination: an experimental study. *Aquatic Toxicology* **39**: 135–149.

Rajagopal, S., Van der Velde, G. and Jenner, H.A. (1997b). Shell valve movement response of dark false mussel, *Mytilopsis leucophaeta*, to chlorination. *Water Research* **31**(12): 3187–3190.

Ramachandra Raju, P., Mangapathi Rao, K., Ganti, S.S. and Kalyanasundaram, N. (1975). Effect of extreme salinity conditions on the survival of *Mytilopsis sallei* Recluz (Pelecypoda). *Hydrobiologia Journal* **46**(2–3): 199–206.

Rao, K.S. and Balaji, M. (1994). Toxicity of copper to *Mytilopsis sallei* (Recluz) and some aspects of its control in Indian waters. pp. 409–415. In: Thompson, M.F., Nagabhushanam, R., Sarojini R. and Fingerman, M. (eds). *Recent developments in biofouling control*. Oxford and IBH, New Dehli, India.

Rash, J.A., Williamson, R.C. and Taylor, S.J. (1996). Proceedings of the Australasian conference on *Spartina* control, Department of Conservation and Natural Resources, Yarram, Victoria.

Rawlings, T.K., Ruiz, G.M., Schoenfeld, S., Dobbs, F.C., Drake, L.A., Huq, A. and Colwell, R.R. (1999). Ecology and ballast-mediated transfer of *Vibrio cholerae* 01 and 0139. pp. 402. In: *First National Conference on Marine Bioinvasions January 24–27, 1999*. Massachusetts Institute of Technology, Massachusetts, USA.

Rebouillon, P., Agostinelli, S., Oddone, L. and Jaffrenou, B. (1999). Un materiel complet et operationnel pour la maitrise et la reduction du developpement de la *Caulerpa taxifolia* en Mediterranee: La cuve electrolytique virtuelle (CEV). In: *Abstracts of the 4th International workshop on Caulerpa taxifolia in the Mediterranean Sea (February 1999).*

Reish, D.J. and Gerlinger, T.V. (1997). A review of the toxicological studies with polychaetous annelids. *Bulletin of Marine Science* **60**(2): 584–607.

Relini, G., Relini, M. and Torchia, G. (2000). The role of fishing gear in the spreading of allochthonous species: the case of *Caulerpa taxifolia* in the Ligurian Sea. *ICES Journal of Marine Science* **57**: 1421–1427.

Rensel, J. and Martin, J. (2000). E. Environmental control and mitigation strategies, In: *Harmful Algal Management and Mitigation- 1999 Conference Draft Guidelines Document*.

<http://vm.cfsan.fda.gov/~frf/hamm99gl.html>.

Reusch, T.B.H. (1998). Native predators contribute to invasion resistance to the non-indigenous bivalve *Musculista senhousia* in southern California. *Marine Ecology Progress Series* **170**: 159–168.

Ribera M. A. and Boudouresque C. F. (1995). Introduced marine plants with special reference to macroalgae: mechanisms and impact. *Progress in Phycological Research* **11**: 187–268.

Ricciardi A. (1998). Global range expansion of the Asian mussel *Limnoperna fortunei* (Mytilidae): another fouling threat to freshwater systems. *Biofouling* **13**(2): 97–106.

Rice Grass Advisory Group (RGAG) (1998). *Strategy for the management of rice grass (Spartina anglica) in Tasmania, Australia*. Department of Primary Industries, Water and Environment, Hobart, Tasmania, Australia. <http://www.dpif.tas.gov.au>

Rigby G. and Hallegraeff G. (1994). The transfer and control of harmful marine organisms in shipping ballast water: behaviour of marine plankton and ballast water exchange trials on the MV 'Iron Whyalla'. *Journal of the Fisheries Society of Taiwan* **1**: 91–110.

Rigby, G.R., Hallegraeff, G.M. and Sutton, C. (1999). Novel ballast water heating technique offers cost-effective treatment to reduce the risk of global transport of harmful marine organisms. *Marine Ecology Progress Series* **191**: 289–293.

Rikard, F.S. and Wallace, R.K. (1997). Management strategies for fouling control in Alabama oyster culture, In: *Abstracts of technical papers presented at the 89th annual meeting of the National Shellfisheries Association, Fort Walton Beach, Florida, April 20–24, 1997. Journal of Shellfish Research* **16**(1): 313.

Roberts, J. and Tilzey, R. (1997). *Controlling carp: exploring the options for Australia*. CSIRO Land and Water, Griffith, New South Wales.132 pp.

Robinson, J.V. and Wellborn, G.A. (1988). Ecological resistance to the invasion of a freshwater clam, *Corbicula fluminea*: fish predation effects. *Oecologia* **77**: 445–452.

Romanova, Z.A., Finenko, G.A. and Shadrin, N.A. (1999). First record of alien species *Beroe ovata* (Ctenophora) near the Crimea Coast. *Vestnik zoologii. Kiev* **33**(6): 90.

Rounsefell, G.A. and Evans, J.E. (1958). Large-scale experimental test of copper sulphate as a control for the Florida red tide. *United States Fish and Wildlife Service Special Scientific Report-Fisheries No.* **270**. United States Department of the Interior, Fish and Wildlife Service, Washington, D.C. 57 pp.

Rudnick, D.A., Halat, K.M. and Resh, V.H. (2000). Distribution, ecology and potential impacts of the Chinese mitten crab (*Eriocheir sinensis*) in San Francisco Bay. *Technical Completion Report. Project Number UCAL-WRC-W-881.* University of California, Water Resources Centre, Berkeley, California. 74 pp.

Ruiz, G.M., Miller, A.W., Walton, W.C. (1998). *The bi-coastal invasion of North America by the European green crab: Impacts and management strategies*. Aquatic Nuisance Species Task Force, Smithsonian Environmental Research Centre, Edgewater, Maryland, USA. 45 pp.

Rygg, B. (1985). Distribution of species along pollution-induced diversity gradients in benthic communities in Norwegian fjords. *Marine Pollution Bulletin* **16**(12) :469–474.

Sanderson, C.J., (1996). A pilot project to examine options for controlling and eradicating the introduced macroalga *Undaria pinnatifida*. *Unpublished Report to CSIRO Marine Research*, Hobart, Australia. 45 pp.

Sanderson, J. C., (1990), A preliminary survey of the distribution of the introduced macroalga, *Undaria pinnatifida* (Harvey) Suringer on the East coast of Tasmania, Australia. *Botanica Marina* **33**: 153–157.

SCC/SCFA 1999: SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions. Final Report to the Standing Committee on Conservation and the Standing Committee on Fisheries and Aquaculture, Canberra, Australia.

Scheduled Wastes Management Group, Environment Australia (1999). Safe handling of organochlorine pesticides on farms. <http://www.environment.gov.au/epg/swm.html#swmg>.

Scott, G.I., Sammons, T.I., Middaugh and D.P., Hemmer, M.J. (1982). Impacts of water chlorination and coliform bacteria of the American oyster, *Crassostrea virginica* (Gmelin). pp. 505–529. In: Vernberg, W.B., Calabrese, A., Thurnberg, F.P. and Vernberg, F.J. (eds). *Physiological mechanisms of marine pollutant toxicity*. Academic Press, New York, USA.

Sengco, M.R., Li, A., Tugend, K., Kulis, D. and Anderson, D.M. (2001). Removal of red- and brown tide cells using clay flocculation. I. Laboratory culture experiments with *Gymnodinium breve* and *Aureococcus anophagefferens*. *Marine Ecology Progress Series* **210**: 41–53.

Sengco, M.R., Li, A. and Anderson, D.M. (2000). The control of harmful algal blooms using clay minerals. In: *Abstracts of the 9th International Conference on Algal Blooms: Harmful Algal Blooms 2000. Hobart, Tasmania, Australia*. <http://www.utas.edu.au/plant_science/HAB2000>.

Schaffelke, B., Murphy, N., Uthicke, S. (2001), Using genetic techniques to investigate the sources of the invasive alga *Caulerpa taxifolia* in three new locations in Australia, *Marine Pollution Bulletin.*

Shatkin, G., Shumway, S.E. and Hawes, R. (1997). Considerations regarding the possible introduction of the Pacific oyster (*Crassostrea gigas*) to the Gulf of Maine: a review of global experience. *Journal of Shellfish Research* **16**(2): 463–477.

Shields, J.D., Buchal, M.A. and Friedman, C.S. (1998). Microencapsulation as a potential control technique against sabellid worms in abalone culture. *Journal of Shellfish Research* **17**(1): 79–83.

Shiganova, T.A. (1998). Invasion of the Black Sea by the ctenophore *Mnemiopsis leidyi* and recent changes in the pelagic community structure. *Fisheries Oceanography* **7**: 305–310.

Simberloff, D. (1997). Eradication. pp. 221–228. In: Simberloff, D., Schmitz, D.C. and Brown, T.C. (eds.). *Strangers in paradise: impacts and management of nonindigenous species in Florida*, Island Press, Washington DC, USA.

Simenstad, C.A., Cordell, J.R., Tear, L., Weitkamp, L.A., Paveglio, F.L., Kilbride, K.M. and Fresh, K.L. (1996). Use of Rodeo and X-77 spreader to control cordgrass (*Spartina alternifolia*) in a southwestern Washington estuary: 2. Effects on benthic microflora and invertebrates. *Environmental Toxicology and Chemistry* **16**(6): 969–978.

Simmons, J. (1998). Algal control and destratification at Hanningfield Reservoir. *Water Science Technology* **17**(2): 309–316.

Sindermann, C.J. (1996). *Ocean pollution: effects on living resources and humans*. CRC Press, Boca Raton, Florida, USA. 275 pp.

Sinner, J., Forrest, B., Taylor, M. and Taylor (2000). A strategy for managing the asian kelp Undaria: Final Report. *Cawthron Report* **578**. Cawthron Institute, New Zealand, 122p.

Skora, K., Olenin, S. and Gollasch, S. (1999). Exotics across the ocean - *Neogobius melanostomus* (Pallas, 1811). pp. 69–73. In: Gollasch, S., Minchin, D., Rosenthal, H., Voigt, M. (eds). *Case histories on introduced species: their general biology, distribution, range expansion and impact.* Department of Fishery Biology, Institut for Marine Science, University of Kiel, Germany.

Sliwa, C. (1999). *An alternative dispersal mechanism for the introduced Japanese macroalga Undaria pinnatifida*. Bachelor of Science Honours Thesis, University of Tasmania, Hobart. 37 pp.

Sloan, N.A. (1985). Echinoderm fisheries of the world: a review. pp. 109–124. In: Keegan, B.F. and O'Connor, B.D.S. (eds). *Proceedings of the Fifth International Echinoderm Conference, Galway, 24–29 September 1984*. A.A. Balkema, Rotterdam.

Smith, C.M. and Walters, L.J. (1999). Fragmentation as a strategy for *Caulerpa* species: fates of fragments and implications for management of an invasive weed. *P. S. Z. N.: Marine Ecology* **20**: 307–319.

Smith, D.L. and Proffitt, C.E. (1999). Among clone differences in *Spartina alterniflora* L. in response to experimental treatments of crude oil and remediation burning. *Gulf Estuarine Reports* **10**(March): 82.

Smith, H.R. and Remington, C.L., (1996). Food specificity in interspecies competition. *BioScience* **46**: 436–447.

Smith, S.S. (1998). Washington State Aquatic Nuisance Species Management Plan. *Prepared by the Washington Aquatic Nuisance Species Planning Committee.* Washington Department of Fish and Wildlife, Washington, USA. <http://www.wa.gov/wdfw/fish-sh.htm>.

Sorentino, C. (1979). The effects of heavy metals on phytoplankton: a review. *Phykos* **18**: 149–161.

Spencer, B.E. (1992). Predators and methods of control in molluscan shellfish cultivation in north European waters. pp. 309–337. In: De Pauw, N. and Joyce, J. (eds). *Aquaculture and the Environment*. *European Aquaculture Society Special Publication no.***16**, Gent, Belgium.

Sprung, M. (1993). The other life: an account of the present knowledge of the larval phase of *Dreissena polymorpha* in the Netherlands. pp. 39–53. In: Nalepa, T.F. and Schloesser, D.W. (eds). *Zebra Mussels: Biology, Impacts and Control*. Lewis Publishers, USA.

Stead, D.H. (1971a). A preliminary survey of mussel stocks in Pelorus Sound. *New Zealand Fisheries Technical Report* **61**: 16.

Stead, D.H. (1971b). Pebrus Sound mussel survey. December, 1969. *N.Z. Fish Tech. Rept* **62**: 28.

Steidinger, K.A. (1975). Origin of Florida red-tides. *Florida Marine Research Publications.* **8**: 4.

Strack, B.H. (2000). Biological control of termites by the fungal entomopathogen, Metarhizium anisopliae. <http://www.utoronto.ca/forest/termite/metani_1.html>.

Stuart, M.D. (1997). The seasonal ecophysiology of Undaria pinnatifida (Harvey) Suringar in Otago Harbour, New Zealand. PhD dissertation. University of Otago, Dunedin, New Zealand. 193 pp.

Stuart, M.D. (2000). Undaria project annual report 1999/2000. *Unpublished Report to Department of Conservation*, New Zealand.

Sunda, W.G. and Guillard, R.R.L. (1976). The relationship between cupric ion activity and the toxicity of copper to phytoplankton. *Journal of Marine Research* **34**: 511–529.

Supan, J.E., Wilson, C.A. and Allen, S.K. (1997). Performance of triploid oysters in Louisiana. In: *Abstracts of technical papers presented at the 89th annual meeting of the National Shellfisheries Association, Fort Walton Beach, Florida, April 20–24 1997. Journal of Shellfish Research* **16**(1): 313.

Sutton C. A. and Bruce B. D. (1996). Temperature and salinity tolerance of the larvae of the northern pacific seastar, *Asterias amurensis. Centre for Research on Introduced Marine Pests. Technical Report No.* **6**. CSIRO Marine Research, Hobart. 26 pp.

Svane, I. (1997). On the ecology of *Carcinus maenas* in European waters. pp. 4–18. In: Thresher, R.E. (ed.). *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced Populations of the European crab, Carcinus maenas. 20–21 March 1997, CSIRO Marine Laboratories, Hobart. Centre for Research on Introduced Marine Pests. Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Takeda, S. and Kurihara, Y. (1994). Preliminary study of management of red tide water by the filter feeder *Mytilus edulis galloprovincialis. Marine Pollution Bulletin.* **28**(11): 662–667.

Taylor, F.J.R. (1968). Parasitism of the toxin-producing dinoflagellate *Gonyaulax catenella* by the endoparasitic dinoflagellate *Amoebophrya ceratii*. *Journal of the Fisheries Research Board of Canada* **25**(10): 2241–2245.

Taylor, F.J.R. (1993). Current problems with harmful phytoplankton blooms in British Columbian waters. pp. 699–703. In: Smayda, T.J., Shimizu, Y. (eds). *Toxic Phytoplankton Blooms in the Sea. Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton. Newport, Rhode Island, USA. 28 October – 1 November 1991*. Elsevier Science Publishers, New York, USA.

Teegarden, G.J. and Cembella. A.D. (1996). Grazing of toxic dinoflagellates (*Alexandrium* spp.) by estuarine copepods: particle selection and PSP toxins in marine food webs. pp. 393–396. In: Yasumoto, T., Oshima, Y. and Fukuyo, Y. (eds). *Harmful and Toxic Algal Blooms. Proceedings of the Seventh International Conference on Toxic Phytoplankton. Sendai, Japan, 12–16 July 1995*. Intergovernmental Oceanographic Commission of UNESCO, Paris, France.

The International Programme of Chemical Safety (1998). *Fact sheet No.* ***87***. <http://www.who.int/inf-fs/en/fact087.htm>.

Thibaut, T. (2000). Need for modelling in the management of an invasive species: the case of *Caulerpa taxifolia* in the Mediterranean Sea. *Abstract of poster at summer meeting of the American Society for Limnology and Oceanography*, Copenhagen, June 2000.

Thomas, H.F.A. and Gerritsen, J.L. (2000). The most effective and environmentally friendly way of killing algae. In: *Abstracts of the 9th International Conference on Algal Blooms: Harmful Algal Blooms 2000. Hobart, Tasmania, Australia*. <http://www.utas.edu.au/plant_science/HAB2000>.

Thresher, R.E. (1997). Proceedings of the first international workshop on the demography, impacts and management of introduced populations of the European crab, *Carcinus maenas. Centre for Research on Introduced Marine Pests. Technical Report No.* **11**. CSIRO Marine Research, Hobart. 101 pp.

Thresher, R. and Grewe, P. (1998). Potential molecular approaches to the environmentally benign management of the Northern Pacific seastar. pp. 59–64. In: Goggin, C.L. (ed.). *Proceedings of a meeting on the biology and management of the introduced seastar Asterias amurensis in Australian waters, 19 May 1998. Centre for Research on Introduced Marine Pests. Technical Report No.* **15**. CSIRO Marine Research, Hobart.

Thresher, R., Goggin, L. and Bax, N. (1998). Chemical approaches to managing populations of the northern Pacific seastar. pp. 49–52. In: Goggin, C.L. (ed.). *Proceedings of a meeting on the biology and management of the introduced seastar Asterias amurensis in Australian waters, 19 May 1998. Centre for Research on Introduced Marine Pests. Technical Report No.* **15**. CSIRO Marine Research, Hobart.

Thresher, R.E., Hewitt, C.L. and Campbell, M.L. (1999). Synthesis: introduced and cryptogenic species in Port Phillip Bay. pp. 283–295. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E. and Martin, R.B. (eds.). *Marine Biological Invasions of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests. Technical Report No.* **20**. CSIRO Marine Research, Hobart

Thresher, R.E., Werner, M., Hoeg, J.T., Svane, I., Murphy, N.E. and Wittwer, C. (2000). Developing the options for managing marine pests: specificity trials on the parasitic castrator, *Sacculini carcini*, against the European crab, *Carcinus maenas*, and related species. *Journal of Experimental Marine Biology and Ecology* **254**: 37-51.

Torchin, M.E., Lafferty, K.D. and Kuris, A.M. (1996). Infestation of an introduced host, the European green crab, *Carcinus maenas*, by a symbiotic nemertean egg predator, *Carcinonemertes epialti. Journal of Parasitology* **82**: 449–453.

Toth, G. and Pavia, H. (2000). Lack of phlorotannin induction in the brown seaweed *Ascophyllum nodosum* in response to increased copper concentrations. *Marine Ecology Progress Series* **192**: 119–126.

Trowbridge, C.D. (1991). Group membership facilitates feeding of the herbivorous sea slug *Placida dendritica*. *Ecology* **72**(6): 2193–2203.

Trowbridge, C.D. (1993). Interactions between an ascoglossan sea slug and its green algal host: Branch loss and role of epiphytes. *Marine Ecology Progress Series* **101**(3): 263–272.

Trowbridge, C.D. (1995). Establishment of the green alga *Codium fragile* ssp. *tomentosoides* on New Zealand rocky shores: current distribution and invertebrate grazers. *Journal of Ecology* **83**(6): 949–965.

Trowbridge, C.D. (1998). Ecology of the green macroalga *Codium fragile* (Suringar) Hariot 1889: invasive and non-invasive subspecies. *Oceanography and Marine Biology. An Annual Review* **36**: 1–64.

Trowbridge, C.D. (1999). An assessment of the potential spread and options for control of the introduced green macroalga Codium fragile ssp. tomentosoides on Australian shores. *Unpublished Report to CSIRO Marine Research*, Hobart, Australia. 43 pp.

Tseng, C.K. (1981). Commercial Cultivation. pp. 680–725. In: Lobban, C.S. and Wynne, M.J. (eds). *The Biology of Seaweeds.* Botanical Monographs Vol. **17**, Blackwell Scientific Publications, Oxford.

Turner, J.T. and Tester, P.A. (1997). Toxic marine phytoplankton, zooplankton grazers, and pelagic food webs. In: Anderson, D.M., Garrison, D.J. (eds). *The ecology and oceanography of harmful algal blooms*. *Limnology and Oceanography* **42**(5)2: 1203–1214.

Tweed, S.M. and Guo, X. (1999). Preliminary evaluation of triploid American oysters, *Crassostrea virginica*, on a mid-Atlantic oyster farm. In: Abstracts of technical papers presented at the 91st annual meeting of the National Shellfisheries Association, Halifax, Nova Scotia, Canada, April 18–22 1999. *Journal of Shellfish Research* **18**(1): 3.

Uchimura, M., Escoubet, P., Gavach, C., Sandeaux, R., Sandeaux, J. and Souard, R. (1996). Action de l'ion cuivrique in vitro sur *Caulerpa taxifolia*. pp. 209–215. In: Ribera M.A., Ballestros E., Boudouresque, C-F., Gomez, A. and Gravez, V., (eds). *Second International Workshop on Caulerpa taxifolia.* Publications Universitat Barcelona.

Uchimura, M., Rival, A., Nato, A., Sandeaux, R., Sandeaux, J. and Baccou, J.C. (2000). Potential use of Cu^{2+}, K^+ and Na^+ for the destruction of *Caulerpa taxifolia*: differential effects on photosynthetic parameters. *Journal of Applied Phycology* **12**: 15–23.

Utting, S. D. and Spencer, B. E. (1992). Introductions of marine bivalve molluscs into the United Kingdom for commercial culture - case histories. pp. 84–89. In: Sindermann, C., Steinmetz, B. and Hershberger, W. (eds). *Introductions and transfers of aquatic species*, Selected Papers from a Symposium held in Halifax, Nova Scotia, 12-13 June 1990, *ICES Marine Science Symposia* **194**.

Van Benschoten, J.E., Jensen, J.N., Lewis, D. and Brady, T.J. (1993). Chemical oxidants for controlling zebra mussels (*Dreissena polymorpha*): a synthesis of recent laboratory and field studies. pp. 599–619. In: Nalepa, T.F. and Schloesser, D.W. (eds). *Zebra mussels: biology, impacts and control.* Lewis Publishers, USA.

Veldhuizen, T.C., Stansih, S. (1999). Overview of the life history, distribution, abundance and impacts of the Chinese mitten crab, *Eriocheir sinensis*.

<http://www.anstaskforce.gov/Mitten%20Crab%20Literature%20Search.htm>.

Venkataraman, L. V., Krishnakumari, M. K. and Suvarnalatha, G. (1994). Algae as tools for biomonitoring and abatement of pesticide pollution in aquatic system. *Phykos* **33**(36557): 171–193.

Waddell, D.C. and Kraus, M.L. (1990). Effects of $CuCl_2$ on the germination response of two populations of the saltmarsh cordgrass, *Spartina alternifolia. Bulletin of Environmental Contaminants and Toxicology* **44**(5): 764–769.

Wai, S.N., Mizunoe, Y. and Yoshida, S. (1999). How do *Vibrio cholerae* survive during starvation, *FEMS Microbiology Letters* **180**: 123–131.

Wakeman, S. and Nishitani, L. (1982). Growth and decline of *Gonyaulax catenella* bloom associated with parasitism. *Journal of Shellfish Research* **2**(1): 122.

Wallentius, I. (1999a). Exotics across the ocean - *Undaria pinnatifida* (Harvey) Suringar, 1872. pp. 11–19. In: Gollasch S., Minchin D., Rosenthal H. and Voigt M., (eds). *Exotics across the ocean: Case histories on introduced species: their biology, distribution, range expansion and impact*, Department of Fishery Biology, Institut for Marine Science, University of Kiel, Germany.

Wallentius, I. (1999b). Exotics across the ocean - *Sargassum muticum* (Yendo) Fensholt, 1955. pp. 21–30. In: Gollasch S., Minchin D., Rosenthal H., Voigt M., (eds). *Exotics across the ocean: Case histories on introduced species: their biology, distribution, range expansion and impact* Department of Fishery Biology, Institut for Marine Science, University of Kiel, Germany.

Walton, W.C. (1997). Attempts at physical control of *Carcinus maenas* within coastal ponds of Martha's Vineyard, MA (northeastern coast of North America). pp. 64–65. In: Thresher, R.E. (ed.). *Proceedings of the First International Workshop on the Demography, Impacts and Management of Introduced Populations of the European crab, Carcinus maenas. 20–21 March 1997, CSIRO Marine Laboratories, Hobart. Centre for Research on Introduced Marine Pests. Technical Report No.* **11**. CSIRO Marine Research, Hobart.

Ward, R.D. and Andrew, J. (1996). Biochemical genetics of the introduced marine fanworm *Sabella spallanzanii. Centre for Research on Introduced Marine Pests. Technical Report No.* **8**. CSIRO Marine Research, Hobart. 35 pp.

Wardle, W.J. (1980). On the lifecycle stages of *Proctoeces maculatus* (Digenea: Fellodistomidae) in mussels and fishes from Galvestion Bay. Texas, *Bulletin of Marine Science* **30**(3): 737–743.

Wassman, E.R. and Ramus, J. (1973). Primary-production measurements for the green seaweed *Codium fragile* in Long Island Sound. *Marine Biology* **21**: 289–297.

WDFW Fact Sheet (1997). <www.wa.gov/wdfw/fish/shelfish/greencrb.html>.

Wecker, M., Strong, D. and Grevstad, F. (2000). Integrating biological control in the integrated pest management program for *Spartina alterniflora* in Willapa Bay. In: *Annual Meeting of the National Shellfisheries Association, Seattle, Washington (USA), March 19–23, 2000. Journal of Shellfish Research* **19**(1): 634.

Welker, M. and Walz, N. (1998). Can mussels control the plankton in rivers? A planktonic approach applying a Lagrangian sampling strategy. *Limnology and Oceanography* **43**(5): 753–762.

Wells, G.P. (1951). On the behaviour of *Sabella. Proceedings of the Royal Society of London (Series B)* **138**: 278–299.

Whayman, D. (1998). The industry perspective. pp. 47–48. In: Goggin, C.L. (eds). *Proceedings of a meeting on the biology and management of the introduced seastar Asterias amurensis in*

Australian waters, 19 May 1998. Centre for Research on Introduced Marine Pests. Technical Report No. **15**. CSIRO Marine Research, Hobart.

Whyte, J. N. C., Davis, J. C. and Forbes, J. R. (1997). Harmful algae in Canadian waters and management strategies. *Ocean Research* **19**(2): 161–171.

Whyte, J.N.C. (1999). Control and mitigation of adverse effects of harmful algae, In: Martin, J.L. and Haya, K. (eds). *Proceedings of the Sixth Canadian Workshop on Harmful Marine Algae*, *Canadian Technical Report of Fisheries and Aquatic Sciences* **2261**: 104.

Willan, R. C. (1987). The mussel *Musculista senhousia* in Australasia; another aggressive alien highlights the need for quarantine at ports. pp. 475–489. In: *Second international symposium on Indo Pacific marine biology*. *Western Society of Naturalists.* **41**

Willan, R. C.; Russell, B. C.; Murfet, N. B.; Moore, K. L.; McEnnulty, F. R.; Horner, S. K.; Hewitt, C. L.; Dally, G. M.; Campbell. M. L.; Bourke, S. T. (2000): Outbreak of *Mytilopsis sallei* (Recluz, 1849)(Bivalvia: Dreissenidae) in Australia. *Molluscan Research* **20**: 25-30.

Wright, D.A. and Magee, J.A. (1997). The toxicity of Endod extract to the early life stages of *Dreissena bugensis*. *Biofouling* **11**(4): 255–263.

Wu, M-Y., Hacker, S., Ayers, D. and Strong, D.R. (1999). Potential of *Prokelisia* spp. as biological control agents of English cordgrass, *Spartina anglica*. *Biological Control* **16**: 267–273.

Yamamuro, M., Oka, N. and Hiratsuka, J. (1998). Predation by diving ducks on the biofouling mussel *Musculista senhousia* in a eutrophic estuarine lagoon. *Marine Ecology Progress Series* **174**: 101–106.

Young, J.S., Adee, R.R., Piscopo, I. and Buschbom, R.L. (1981). Effects of copper on the sabellid polychaete, *Eudistylia vancouoveri*. II. Copper accumulation and tissue injury in the branchial crown. *Archives of Environmental Contamination and Toxicology* **10**: 87–104.

Zaitsev, Y. P. (1992). Recent changes in the trophic structure of the Black Sea. *Fisheries Oceanography* **1**(2): 180–189.

Zarkanellas, A.J. (1979). The effects of pollution-induced oxygen deficiency on the benthos in Elefsis Bay, Greece. *Marine Environmental Research* **2**: 191–207.

Zhang, F. and Dickman, M. (1999). Mid-ocean exchange of container vessel ballast water. 1: seasonal factors affecting the transport of harmful diatoms and dinoflagellates. *Marine Ecology Progress Series* **176**: 243–251.

Zhiming, Y., Jingzhong, Z. and Xiaoxia, S. (2000). Progress of red tide control with clays. In: *Abstracts of the 9th International Conference on Algal Blooms: Harmful Algal Blooms 2000. Hobart, Tasmania, Australia*. <http://www.utas.edu.au/plant_science/HAB2000>.

Zuljevic, A. and Antolic, B. (1999a). Appearance and eradication of *Caulerpa taxifolia* in the Barbat Channel. In: *Abstracts of the 4th International workshop on Caulerpa taxifolia in the Mediterranean Sea, February 1999.*

Zuljevic, A. and Antolic, B. (1999b). Partial eradication of the *Caulerpa taxifolia* in Starigrad Bay. In: *Abstracts of the 4th International workshop on Caulerpa taxifolia in the Mediterranean Sea, February 1999.*

Zuljevic, A. and Antolic, B. (1999c). Predation of the Mediterranean ascoglossans on the introduced tropical species *Caulerpa taxifolia*. In: *Abstracts of the 4th International workshop on Caulerpa taxifolia in the Mediterranean Sea, February 1999*.

APPENDIX 1. AVAILABILITY AND REGULATIONS FOR THE USE OF VARIOUS CHEMICALS FOR CONTROL IN AUSTRALIAN MARINE AND ESTUARINE ENVIRONMENTS

1 Regulations

The total number of chemicals on the market now stands close to 100,000. The value of the total global annual production is about 1.5 trillion US dollars (IPCS, 1998). The use of appropriate treatment chemicals needs to be considered within the constraints of national and international accepted practices, when responding to a marine pest incursion. In Darwin in 1999, the response management taskforce to the *Mytilopsis* sp. incursion was not aware that discharge of copper sulphate into marine waters was in breach of International Maritime Organisation (IMO) conventions. In addition, a number of alternative chemicals that may have been useful during the treatment of the mussel incursion could not be used as they were not accredited for use in Australia (Ferguson 2000).

Australian chemical regulations include a wide range of chemicals including dyes, solvents, plastics, laboratory chemicals, paints, cleaning agents and cosmetics. Chemical regulation in Australia is generally managed by the Commonwealth, after which the States and/or Territories manage the chemical from point of sale to use through a range of legislation. Many of the key laws for administering chemicals have only been enacted in the past decade. Recent changes to Australia's chemical management infrastructure include a large range of new State and Territory legislation directed at improving the management of chemicals. Fields covered include occupational health and safety, environmental protection, transport and waste (for list of relevant legislation, see Environment Australia 1998, Appendix 1).

1.1 Commonwealth legislation

Four key national schemes correspond to the four common applications of chemicals: agriculture, industry, pharmaceuticals and food. The four key national schemes are:

1. National Registration Scheme for Agricultural and Veterinary Chemicals (NRA), established in 1994, fully operative since 1995;
2. National Industrial Chemicals Notification and Assessment Scheme (NICNAS), established in 1990 and administered by the NOHSC;
3. Therapeutic Goods Administration (TGA) for pharmaceuticals and regulation of poisons, established in 1989;
4. Australian and New Zealand Food Authority (ANZFA) for food additives and contaminants established in 1991 (Environment Australia 1998).

Industrial and agriculture/veterinary chemicals are addressed in terms of public health, OH&S, environmental health, safety of non-target plants and animals, chemical efficacy and possible trade effects. Pharmaceuticals and food additive schemes focus on human health. Each of the schemes provides a consistent set of standards to be applied across jurisdictions in the risk management of chemicals. The first schemes are of most relevance to potential use of chemicals for marine pest eradication.

Agricultural and industrial chemicals are subject to assessments and controls on: importation, manufacture and use specifically designed to protect human health in occupational settings. Material Safety Data Sheets (MSDS), consistent labelling and risk or safety phrases are developed by industry and approved by government. MSDSs are available from the manufacturers, vendors, NOHSC and some Internet sources. The NOHSC website contains a list of Designated Hazardous Substances and is the first reference point for suppliers determining if any substance they supply is hazardous and appropriate risk and safety information.

Agricultural and veterinary chemicals are assessed in addition by the National Drugs and Poisoning Scheduling Committee (NDPSC), and recommended for scheduling in the Standard for Uniform Schedule of Drugs and Poisons (SUSDP) as necessary (Environment Australia 1998).

A large number of chemicals were approved for use prior to the introduction of NICNAS in 1990. NICNAS can review these existing approvals through nomination to the list of Priority Existing Chemicals by concerned persons. For example sodium hypochlorite is on the candidate list of existing chemicals, a list of chemicals that will be considered for assessment and declaration as priority existing chemicals by NICNAS (Environment Australia 1998).

The potential for a chemical to impact adversely on the environment or on public health is a core assessment topic for both pesticides and industrial chemicals (Environment Australia 1998). Both the NRA and NICNAS rely on Environment Australia to assess the potential impact of a chemical on Australia's environment, the Commonwealth Department of Health and Family Services to evaluate potential impacts on human health effects, and the National Occupational Health and Safety Commission (NOHSC) (formerly Worksafe Australia) to assess the impacts on workers' safety.

Environmental assessment is made on the potential of the chemicals to affect ecosystems, based on exposure and toxicity data from testing with such organisms as mammals, birds, fish, insects, crustaceans, plants. These are conducted by the Risk Assessment and Policy Section (RAPS) of Environment Australia (EA website). Australia is currently establishing uniform air and water standards for certain chemicals across all jurisdictions through a joint Commonwealth, State and Territory process under the National Environmental Protection Council (NEPC). The national air standards focus on public health, whereas the water standards are concerned with protecting the wider environment.

The National Residue Survey (NRS) is conducted by the Commonwealth Department of Agriculture, Fisheries and Forestry's Bureau of Resource Sciences. The NRS monitors Australian raw food commodities on both domestic and export markets for chemical residues including agricultural and veterinary chemicals used in food production. NRS surveys provide a snapshot of the chemical residue status of agricultural commodities (NRS website).

1.2 State and Territories legislation

The States and Territories control the use of industrial chemicals mainly through prohibition, application of occupational exposure standards and health surveillance. Many controls focus on the areas of worker safety, transport, public health, environmental protection and the handling of hazardous substances, including waste disposal procedures.

The States and Territories identify chemicals including classes of chemicals that can or cannot be released to the environment under certain operating conditions in their respective jurisdictions. In addition, States and Territories are responsible for the safe transport and storage of chemicals through various acts. Land transport of dangerous goods is controlled under the Australian Code for the Transport of Dangerous Goods based on the UN Recommendations on Transport of Dangerous Goods and is currently being adopted uniformly by all States and Territories (eg. HAZCHEM codes on labels) (Environment Australia 1998).

1.3 International agreements

A number of intergovernmental bodies exist to examine chemical safety and to provide information between countries. Several of these are discussed below and more relevant websites are listed at the end of this document. The Inter-Organisation Program for the Sound Management of Chemicals (IMOC) was established in 1995 to serve as a mechanism for coordinating efforts of intergovernmental organisations in the assessment and management of chemicals. The participating organisations are UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD (IOMC website).

In 1998, representatives of 95 countries reached an agreement on the Convention of Prior Informed Consent (PIC) in the trade of certain hazardous chemicals and pesticides. The major aim of PIC is to promote shared responsibility between exporting and importing countries in protecting human health and the environment from the potential hazards of dangerous chemicals. Australia is yet to sign the treaty, although it previously supported the voluntary form of PIC (Chemicals and the Environment Branch, EA website). Full details on the Convention can be found at the joint FAO/UNEP PIC website.

Concise International Chemical Assessment Documents (CICADS) are publications from the International Programme on Chemical Safety (IPCS) as cooperative program of the WHO, UNEP and the International Labour Organisation. These documents provide summaries of the potential effects of chemicals on human health and the environment and are available from the CICADS website. Information on tributyltin oxide is provided.

2 Chemicals registered under NRA

The NRA Pubccris database available on their website contains the chemicals registered in Australia. The ag/vet chemicals mentioned in this review registered in Australia by the NRA are shown in Table A1. Some chemicals are registered for use in some States or Territories and not others. Some chemicals are approved for restricted purposes only.

Table A1. Agricultural/veterinary chemicals mentioned in this review and registered by the NRA in Australia (August 2000).

Active ingredient	# listed products	Type of chemical	Comment
2,4-D	93	Herbicide	
Atrazine	40	Selective systematic herbicide	NRA Review, Nov. 1997
Carbaryl	62	Insecticides, fungicides, bactericide	Organocarbamate pesticide
Chlorpyrifos	164	Organophosphate insecticides, termiticide	NRA Review, January 2000
Coptrol Aquatic Algicide®	1	Algicide; copper as mixed copper chelates	
Dichlobenil	4	Herbicide	eg. Casuron in UK
Diflubenzuron	9	Insect growth regulator	eg. Dimilin (TH6040)
Diquat	5	Herbicide	
Diuron	76	Herbicides, algicides and antifoulants, with other chemicals eg. copper	
Fluazifop	3	Herbicide	eg. Fusilade
Glyphosate	201	Herbicide	eg. Roundup-Aus, Rodeo-USA
Lindane	1	Organochlorine insecticide	limited use (QLD only)
Rotenone	28	Insecticide, fungicide, piscicide	
Simazine	52	Herbicides and algicides	

The following herbicides and piscicides are not listed on the NRA website and are probably not registered in Australia: gluphosinate, 2,2-dichloroproionic acid, sodium salt (eg. Dalapon in UK), Feneron, TFM and Antimycin.

Many organochlorine pesticides (OCPs) have been deregistered in recent years, including the following pesticides mentioned in this review: chlorodane, dieldrin, DDT, endrin, and pentochlorophenol (including its salts eg "Santobrite" sodium pentochlorophenate) (Scheduled

Wastes Management Group 1999). Endosulphan – registration suspended in June 2000, current stocks to be phased out (NRA Review of Endosulphan; NRA Media release 00/7 June 2000). Lindane and mirex are among the few organochlorine pesticides (OCPs) still registered for limited use (ie. Lindane in Queensland only) (Scheduled Wastes Management Group 1999). The registration of the organophosphate pesticide Azinophos-ethyl has recently been cancelled (NRA media release 99/10 August 1999).

The NRA Review of Glyphosate (June 1996) included a warning statement on all agricultural glyphosate product labels precluding use on or adjacent to waterways ie. ditches, drains, lakes etc. unless authorised; and only allowing use in sensitive aquatic situations where it can be demonstrated the glyphosate formulation does not pose a significant risk to the aquatic environment.

Registered agricultural/veterinary chemicals carry a NRA-approved label that provides users with instructions designed to minimise impacts on health, the environment and trade. Pesticide use must follow the instructions and be used for the express purpose stated on the label. Special provisions exist under legislation administered by the NRA to allow people to use ag/vet chemicals in a way that is not described on the approved label. The NRA national permit scheme exists for when situations arise where it may be necessary to use an unregistered product or a registered product in an unapproved manner (off-label use). This includes emergencies such as outbreaks of contagious disease or exotic pests for which no registered products exist. Permits legalise the use of these products in ways that otherwise would be an offence. Assessments of permit applications for emergency use are given the highest priority and are usually processed within 5-10 days (NRA website). For example, The Rice Grass Advisory Group has obtained an exclusive permit to use Fusilade® (fluazifop -*p*-butyl) for the control of rice grass in Tasmania for a limited period, although it is not licensed for use in the coastal environment. As part of the permit conditions, herbicide use is restricted to maximum allowable volume pers unit area and application in strips and blocks rather than blanket spraying (RGAG 1998). Enquires regarding permits may be directed to NRA’s permit evaluators or directed to the appropriate State government departments (see Relevant contacts)

Penalties apply for misuse of pesticides, with higher penalties for wilful or negligent misuse offences. For example, in NSW it is illegal to possess (with intent to use), prepare for use, or use a pesticide unless it is registered by the NRA or covered by a NRA permit (NSW EPA website). Under the ACT Environment Protection Regulations a registered or permitted ag/vet chemical product is assumed to cause environmental harm if it is not registered by the NRA or if use exceeds levels authorised by the NRA (ACT legislation website).

3 Designated Hazardous Substances

The following chemicals mentioned in this review appear on this NOHSC Designated Hazardous Substances List: tributyltin compounds, copper sulphate, copper oxide, copper(1)chloride, potassium permanganate, acridine, ammonium chloride, ammonia, phenol and related compounds, pentachlorophenol and its alkali salts, hydrochloric acid, benzene and related compounds, creosote, chlorine, chloramine, sodium hypochlorite, calcium hypochlorite, sodium azide, bromine and hydrogen peroxide. This means that care must be taken in the use of these chemicals (see MSDS sheets etc.).

4 Relevant websites and contacts

Few of the States and Territories provide a list of which chemicals are permitted for use and which are not on their website. Direct contact with the individual States is necessary to obtain full information. Searching the NRA database may give some indication of allowed products (but not methods of use or restrictions).

4.1 Commonwealth

Environment Australia (EA):

http://www.ea.gov.au/index.html

Chemicals and the Environment Branch

Enquiries: 02 6274 1111

Risk Assessment and Policy Section, Environmental Protection Group

Enquiries: 02 627401643

Legislation: http://www.ea.gov.au/about/legislation.html#environment

National Registration Authority for Agricultural and Veterinary Chemicals) (NRA)

http://www.nra.gov.au/index.html

NRA Pubccris database: http://www.nra.gov.au/pubcris/subpage_%20pubcris.shtml

Switch and general enquiries 02 6272 5158

Registered chemicals- approved uses, number of products (02) 6272 3894

Permits for trial or off-label use of chemicals (02) 6272 3726

Aquaculture chemicals (permits for use) (02) 6272 3895

National Occupational Health and Safety Commission (NOHSC):

http://www.nohsc.gov.au/

List of Designated Hazardous Substances:

http://www.nohsc.gov.au/ohsinformation/nohscpublications/fulltext/techreports/nohsc10005_02.htm

Enquiries: 02 9577 9555

National Industrial Chemicals Notification and Assessment Scheme (NICNAS):

http://www.nicnas.gov.au/

Enquiries: 02 9577 9400

Therapeutic Goods Administration (TGA)

http://www.health.gov.au/tga

Infoline: 1800 020 653

Australian and New Zealand Food Authority (ANZFA):

http://www.anzfa.gov.au/

Enquiries: 02 6271 2222

Agriculture, Fisheries and Forestry - Australia

http://www.affa.gov.au/index.cfm

General enquiries: 02 6272 3933

Australian Quarantine and Inspection Service (AQIS)

http://www.daff.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A00830

General free call number: 1800 020 504

Bureau of Resource Sciences, National Residue Survey (NRS):

http://www.affa.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A05740

Phone: 02 6272 5987

4.2 State and Territories

Tasmania

Department of Primary Industries Water and Environment:

http://www.dpif.tas.gov.au

Enquiries: 03 6233 8011

General enquiries (within Tasmania): 1300 368 550

Chemical use permits: 03 6233 3565

Legislation: http://www.thelaw.tas.gov.au/

Victoria

Environment Protection Authority, Victoria:

http://www.epa.vic.gov.au/

Information Centre: 03 9628 5391

Legislation: http://www.dms.dpc.vic.gov.au/l2d/P/ACT01104/2_3.html

Agriculture Victoria

Chemical use permits: 03 9651 7137

New South Wales

Environment Protection Authority, NSW:

http://www.epa.nsw.gov.au/index.asp

EPA Pesticides Unit: 02 9995 5799

EPA Pollution Line: 131555 (cost of a local call)

Chemical use permits: 02 9325 5720

Legislation: http://www.epa.nsw.gov.au/legal/envacts.htm

Queensland

Environment Protection Authority, Queensland Parks and Wildlife Service, Queensland:

http://www.env.qld.gov.au/environment/

EPA Advisory Service: 1800 501 087

Legislation: http://www.legislation.qld.gov.au/

Department of Primary Industries

Chemical use permits: 07 3239 3936

South Australia

Environment Protection Authority South Australia:

http://www.environment.sa.gov.au/epa/

Enquiries: 08 8204 2033

Department of Primary Industries

Chemical use permits: 08 8226 0551

Legislation: http://www.environment.sa.gov.au/epa/legislation.html

Western Australia

Department of Environmental Protection:

http:www.environ.wa.gov.au

Enquiries: 08 9222 7000

Agriculture Western Australia

Enquiries: 08 9368 3688

Chemical use permits: 09 9368 3815

Northern Territory

Environmental Heritage Division, Department of Lands, Planning and Environment

Enquiries: 08 8924 4140

Department of Primary Industries and Fisheries

Chemical use permits: 08 8999 2272

Australian Capital Territory

Environment ACT:

Enquires: 02 62072151

Department of Urban Services

Chemical use permits: 02 6207 2643

Legislation: http://www.austlii.edu.au/au/legis/sa/consol_reg/epr393/s15.html

4.3 International Organisations

Inter-Organisation Program for the Sound Management of Chemicals (IMOC)

http:www.who.int/iomc

Organisation for Economic Co-operation and Development (OECD)

http://www.oecd.org/ehs/chem2.htm

The OECD maintains active chemical and pesticide programs through the Environment, Health and Safety Division of its Environment Directorate.

Intergovernmental Forum for Chemical Safety (IFCS)

http://www.who.int/ifcs/

The Intergovernmental Forum on Chemical Safety (IFCS) was created by the International Conference on Chemical Safety held in Stockholm in April 1994. The IFCS was established as new mechanism for cooperation among governments for the promotion of chemical risk management and the environmentally sound management of chemicals. Environment Australia is closely involved with the work of the IFCS.

UNEP Chemicals

http://www.irtpc.unep.ch/

Food and Agriculture Organisation (FAO)

http://www.fao.org

Convention of Prior Informed Consent (PIC)

http://irptc.unep.ch/pic/

Concise International Chemical Assessment Documents (CICADS) from the International Programme on Chemical Safety (IPCS)

http:www.int/dsa/cicads.htm

European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC)

http://www.who.int/ina-ngo/ngo/ngo012.htm

APPENDIX 2. GLOSSARY OF TERMS

ABWMAC: Australian Ballast Water Management Advisory Council

Advection: The horizontal or vertical transfer of material, heat, etc., brought about by the mass movement of the oceans, eg. in currents.

Active ingredient (of a herbicide/pesticide): The substance within the formulation that kills (Horlock 1998).

Allelopathy: The deleterious process by which one organism influences others nearby through the escape or release of toxic or inhibitory substances into the environment.

Algicide: That which kills algæ; specifically, a preparation used for destroying algæ.

Anthropogenic: Having its origin in the activities of man.

ANZFA: Australian and New Zealand Food Authority

AQIS: Australian Quarantine and Inspection Service

Aquaculture: The farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators etc. Farming also implies individual or corporate ownership of the stock being cultivated (www.fao.org/docrep/t8582e/t8582e03.htm)

Biocide: The destruction of living species by indirect chemical means.

Biofouling (biological fouling): Growth of sessile algae and animals, especially on vessel hulls, artificial underwater structures, or in water-intake apparatus

Biological control: Control of pests and weeds by other living organisms, usually other insects, bacteria or viruses or by biological products such as hormones (Lawrence 1989).

Carbamate: A salt of carbamic acid, as ammonium carbamate, $CONH_2ONH_4$. Where carbamide is the analytical name of the organic compound urea, $CO_2(NH_2)$, as a primary diamide of Carbonyl.

Carcinogen: A substance or agent that produces cancer.

CCA: A solution of copper, chrome or arsenic salts used in chemical treatment of timber.

Classical biological control: Uses host specific organisms from the target species native range to suppress the population of the introduced pest.

Chemoprophylaxis: The preventive treatment of disease using chemicals.

Control (noun): The fact of controlling, or of checking and directing action; the function or power of directing and regulating; domination, command, sway.

CRIMP: Centre for Research on Introduced Marine Pests

Cryptogenic species: Where neither a species native or introduced status can be confirmed.

CSIRO: Commonwealth Scientific and Industrial Research Organisation

Diquat: A quaternary compound with herbicidal properties.

DDT: Dichlorodiphenyltrichloroethane, a white, crystalline, chlorinated hydrocarbon used as an insecticide in the form of a powder, an aqueous emulsion, or a non-aqueous solution.

DNRE: Department of Natural Resources and Environment, Victorian Government.

DPIWE: Department of Primary Industries Water and Environment, Tasmanian Government.

EA: Environment Australia, Commonwealth Department

Endophyte: Bot. [Gr. plant], a plant growing inside another, an internal fungus.

EPA: Environmental Protection Authority

Eradicate: To remove entirely, extirpate, get rid of.

Environmental weed: An unwanted plant damaging to the environment in which it is located (Horlock 1998).

Exotic: Non-native, usually implying introduction through human activity (Horlock 1998) (in popular language with added sense of ‘not naturalised or acclimatised’).

FAO: Food and Agriculture Organisation, a United Nations Organisation

Feral: Of an animal: wild, untamed. Of a plant, also (rarely), of ground: uncultivated. Now often applied to animals or plants that have lapsed into a wild from a domesticated condition.

Glyphosate: A non-selective systemic herbicide, particularly effective against perennial weeds, and used (in solution or as the isopropylamine salt) in various commercial weedkillers; N-(phosphonomethyl) glycine, $C_3H_8NO_5P$.

Herbicide: Any chemical agent that is toxic to some or all plants and is used to destroy unwanted vegetation.

ICES: International Council for the Exploration of the Sea

IFREMER: Institut Francais de Recherche pour L’Exploitation de al Mer

IMO: International Maritime Organisation

Indigenous: Naturally distributed within a specific geographic region (Horlock 1998).

Inducible: Capable of being brought on, brought about, or caused.

Integrated Pest Management (IPM): Primarily using biological and ecological interventions to control pest species. Can also involve the use of mechanical/physical and chemical controls.

Introduced (exotic) species: “Those species that did not occur geographically within a particularly define region prior to some predetermined period” (Les and Mehrhoff (1999).

Management: The application of skill or care in the manipulation, use, treatment, or control (of things or persons), or in the conduct (of an enterprise, operation, etc.).

Mitigate/mitigation: To lessen the effects.

Molluscide: Any substance used to kill molluscs.

MSDS: Material Safety Data Sheets

NDPSC: National Drugs and Poisoning Scheduling Committee

NEPC: National Environmental Protection Council

NICNAS: National Industrial Chemicals Notification and Assessment Scheme

NRA: National Registration Authority for Agricultural and Veterinary Chemicals

NRS: National Residue Survey

NOHSC: National Occupational Health and Safety Commission (formerly Worksafe Australia)

Noxious species: A species identified under government legislation as harmful or destructive to an area, which may be the subject of regulations governing attempts to control it.

OH&S: Occupational Health and Safety

PAC: Polyhydroxy aluminium chloride, a surfactant.

Parasite: An animal or plant that lives in or upon another organism (technically called its host) and draws its nutriment directly from it. Also, extended to animals or plants that live as tenants of others, but not at their expense (strictly called commensal or symbiotic).

Pathogen: Any agent that causes disease, especially a microorganism.

PCP: Pentachlorophenol, usually as sodium pentochlorophenate.

Pest: Any thing or person that is noxious, destructive, or troublesome; a bane, ‘curse’, ‘plague’.

Pesticide: A substance for destroying pests, especially insects.

Phytohormone: A hormone produced by an alga

PIC: Prior Informed Consent

Piscicide: A substance that kills fish.

Exotic pathogen: A pathogen taken from the target species native range.

Predator: Any organism that catches and kills other organisms for food (Lawrence 1989).

Saponin: Any of a large class of steroid glycosides obtained from plants and some animals, which are toxic (especially to fish), causing hæmolysis, and are characterised by the production of a soapy solution in water.

SCC: Standing Committee on Conservation

SCFA: Standing Committee on Fisheries and Aquaculture

sp.: Abbreviation for species (singular)

spp.: Abbreviation for species (plural)

ssp.: Abbreviation for subspecies

SUSDP: Standard for Uniform Schedule of Drugs and Poisons

Surfactant: A surface-active agent, a substance that lowers the surface tension of water. All materials that have surface activity, including wetting agents, dispersants, emulsifiers, detergents and foaming agents.

Taxon/taxa: A taxonomic group(s), as a genus or species.

TGA: Therapeutic Goods Administration

Transgenic: Of an organism: containing genetic material into which DNA has been artificially introduced into the germ line. Also applied to the cells of a transgenic organism.

Triploid: (Made up of somatic cells) containing three sets of chromosomes.

TBT: Tributlytin.

WHO: World Health Organisation