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REDUCING THE IMPACT OF SHIP-BORNE MARINE INTRODUCTIONS: FOCAL OBJECTIVES AND DEVELOPMENT OF AUSTRALIA'S NEW CENTRE FOR RESEARCH ON INTRODUCED MARINE PESTS

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Summary

Preventing further introductions of exotic marine species and controlling those already in Australian waters requires research on the development of more effective barriers, on assessing which exotic species are already present and the risks they pose for human health, marine industries and the marine environment, and on developing an effective means of controlling, if not eradicating them. Australia has a long history and considerable success in applying research to meet these needs for introduced terrestrial pests, but efforts to limit the impacts of marine introductions have to date focused largely on barrier controls. The development of a co-ordinated, broadly-based research effort has also been hampered by the lack of any central body with clear responsibility and adequate funding to address the problem. Two recent initiatives by the Federal Government - the establishment of the Interim Australian Ballast Water Management Advisory Council and the provision of funds for a CSIRO Centre for Research on Introduced Marine Pests - are significant moves towards redressing this situation.

Introduction

As a result of Australia's geographical isolation, its dependence on shipping for import and export, and marine quarantine procedures that world-wide are poorly developed, Australia now hosts over 70 known exotic marine species, of which around 20 are believed to have been introduced in ships' ballast water (Jones 1991) (Table 1). Although no detailed surveys have yet been done, overseas experience (Carlton, 1989) suggests that the actual number of introduced species in Australian ports is much higher. Supporting this, a preliminary assessment of a southern Australian port suggests that in some habitats, as much as a third of the fauna may be introduced.

In most cases the threat posed by these exotic species is not known. However, three introductions - the toxic dinoflagellate, *Gymnodinium catenatum*, the alga, *Undaria pinnatifida*, and the Northern Pacific seastar, *Asterias amurensis* - alone could cost the shipping, mariculture and fishing industries millions of dollars annually. Both *Undaria* and *Asterias* have the potential to cause major changes to the structure of temperate Australian coastal marine ecosystems. The potential impacts of other previously cryptic exotic species, such as the Mediterranean fan worm, *Sabella spallanzanii*, and the European shore crab, *Carcinus maenas*, are only now being assessed. Reflecting these concerns, the Australian Coastal Zone Inquiry (Resource Assessment Commission, 1993) highlighted the need for research directed at two areas: (i) preventing new introductions and (ii) assessing and minimising the impacts of existing introductions.

Preventing new introductions

Australia has taken a high profile internationally in an effort to minimise the risks of ballast water introductions. The Australian Quarantine and Inspection Service (AQIS), through its chairmanship of the Marine Environment Protection Committee of the International Maritime Organisation, has been a strong advocate for international controls on the discharge of ballast water. As well, in 1994 AQIS convened a national Ballast Water Symposium in Australia, to highlight the importance of the issue and to progress action on it. The major outcome of the symposium was a *Draft National Strategy on Ballast Water Management*.

The draft strategy recommended the establishment of an Australian Ballast Water Management Advisory Council, supported by a Research Advisory Group and core funding for research. Pending national endorsement of this strategy, an interim council has been set up to progress urgent issues. The interim council consists of government departments with a stake in the ballast water issue (quarantine, transport, marine safety, environment), key industry groups (shipping, port authorities, fishing and mariculture industries) and a senior science representative (CSIRO). The Research Advisory Group consists primarily of industry representatives and a broader spectrum of relevant science agencies. The interim council has focused its attention on three objectives:

- allocation of responsibility for ballast water management;
- development of a secure funding base for long-term research; and
- development of a strategic research plan.

Responsibility for ballast water management

The question of who should, or in fact, who can take responsibility for developing and enforcing ballast water regulations or guidelines in Australia has yet to be resolved. Cogent arguments can be made for this role being either a federal or a state responsibility. The underlying problem is that the plethora of acts and regulations that are relevant to introduced marine pests and their transport vectors are administered by a number of different state and federal departments. All have some regulatory responsibilities in relation to the issue, but it is not clear where the authority to respond lies, or which agency can respond most effectively. A similar problem arises in relation to the role of port authorities, the potential implementers of any management strategy. These authorities differ in their responsibilities from state to state and it is unclear if any have the legislative authority to enforce ballasting controls. The interim council has invited comments on this issue from all relevant state departments and has established a sub-committee, chaired by a state representative, which will make recommendations to the Council and, through it, to the federal government for implementation.

Funding for long-term research

The Australian Government has a "user-pays" approach to the provision of government services and research. This means, in the case of marine introductions, that if international shipping or its clients are viewed as the main perpetrators of the problem, they should bear the brunt of the cost of remediation and control. Such an approach, however, presupposes a capacity to allocate responsibility for specific introductions, which requires unequivocal identification of transport vectors and a detailed knowledge of high risk vessels and shipping routes. An alternative approach, canvassed by the council, is a broadly based levy on the shipping industry. Opponents of the levy rightly point out that it imposes an additional cost on "good corporate citizens", who already take suitable precautions to minimise risks, while providing no incentive for those "less responsible citizens" to do likewise. The issue is

further complicated by different levels of interest shown by relevant industries in funding baseline as opposed to barrier-related research, and meeting costs associated with inspection, verification, and barrier co-ordination.

Development of a strategic research plan

Virtually everyone involved in the issue sees research and technology as the keys to resolving the introduced pest problem. The research required falls into two broad categories: baseline and barrier development. The first relates to the state of the current problem: How many ports are infected, and by what?, What is the major transport vector ?, and What international routes and carriers pose the greatest risks? The second deals with prospects for risk minimisation through development of a decision support system for re-ballasting, and by examining management options at the port of up-take, during transport, and in the receiving port. This approach is broadly consistent with that taken elsewhere (Carlton, 1989).

The interim council plans to have these issues resolved, and a draft strategic plan in place, by the end of 1995.

Assessing and minimising the impacts of existing introductions

The evaluation and control of introduced marine pests requires a multi-disciplinary approach involving areas as diverse as taxonomy, environmental impact assessment, economics and engineering. In 1994, the Australian Government allocated funds to the CSIRO (Commonwealth Scientific and Industrial Research Organisation) to conduct this research on a national scale. To do so, a Centre for Research on Introduced Marine Pests (CRIMP) was set up within the CSIRO Division of Fisheries. The objectives of the Centre are:

(i) To develop and promote implementation of tools for earlier warning, better prediction, and more effective assessment of risks and costs of marine pest species introduced to Australia.

(ii) To develop new methods or improve existing measures to control the spread and minimise the impacts of introduced marine species.

Achievement of these objectives involves evaluating the environmental and economic threats posed by known introduced pest species; developing cost-effective monitoring programs for early detection of these species in high-risk areas; providing the ecological basis for assessing the effectiveness of existing and new control measures; and developing and promoting new control measures nationally and internationally.

CRIMP is taking a staged approach to the problem, focusing on key objectives and collaborating, wherever possible, with other research initiatives in order to maximise the value of the research dollar. Discussions with the centre's primary clients lead to a research plan that has three main thrusts: (i) an assessment of the scale of the problem in Australian waters; (ii) investigation into ways to minimise the risk of domestic translocation of exotic species; and (iii) the development of biological controls against pest species.

Assessing the scale of the introduced species problem

To assess the number, diversity and distribution of the introduced marine species in Australian waters, CRIMP is undertaking three interrelated studies, two of which will be jointly funded with other agencies:

(i) *Intensive port surveys.* These surveys will provide an indication of the magnitude of the problem in a small number of representative ports. The first port to be examined will be Port Phillip Bay, in south-eastern Australia. Port Phillip Bay was chosen because of the availability of good local taxonomic knowledge, access to support infrastructure, its role as a major port for both domestic and international shipping, and a historical data base against which the current species assemblage can be compared. For logistical and taxonomic reasons, the survey will concentrate on a few major groups - primarily fish, selected macro-invertebrate groups and the macro-algae – and will be largely qualitative (mainly presence-absence). The Port Phillip Bay study will be completed by the end of 1996, after which the focus will shifted to a tropical port (most likely Darwin).

(ii) *National ports survey.* CRIMP and the Australian Association of Port Management Authorities are jointly funding a survey of all major shipping ports in Australia. The survey will be semi-quantitative, and have three objectives:

- to determine the geographical distribution of a set of identified "pest" and exotic species (Table 1);
- to obtain opportunistic information on other introduced species in the ports; and
- to make a preliminary risk assessment for each port on likelihood of translocation of existing pests and to recommend ways to reduce these risks.

The national port survey will start in 1995, will be completed by 1997, and may lead to an on-going monitoring program.

(iii) *Community-based coastal monitoring.* In 1995, the Australian Government provided funding for a national 'Coast Care' initiative, to facilitate community involvement in coastal management. As part of this program, CRIMP and the relevant commonwealth department are developing a national "early warning" network for introduced species. Fifty four regional co-ordinators are being appointed, who will develop links between CRIMP (and other scientific agencies) and local community groups, such as dive clubs, fishing groups and schools. CRIMP will provide technical expertise and identification material to support the efforts of volunteers to map the presence of known pests and keep an eye open for new ones. It is hoped that the broad geographical coverage of the network will make possible the rapid detection of any new introductions and provide opportunities to eradicate such species before they can establish and spread.

Minimising the domestic translocation of exotic species

CRIMP is progressing this issue in three ways. First, studies are underway to assess the relative importance of hull fouling and domestic ballast water exchange in the coastal transport of the main pest species. This study involves surveys of hulls for fouling organisms, particularly known pest species, and experiments to determine whether the larvae of these species survive in and remain viable in the ballast tanks of coastal vessels. Preliminary indications are that hull fouling is likely to be the main transport vector for several of the major pest species.

Second, discussions are underway with mariculture co-operatives to develop treatment protocols to minimise the risk of accidental transport of eggs, larvae or juveniles of pest species in the live fish or shellfish trade.

Third, we are initiating a long-term project to look at the impact of port management practices on the colonisation success of invading species. Theoretical and empirical

considerations suggest that vacant habitat created by disturbance may be a major factor in facilitating colonisation by exotic species. Field and experimental studies are being planned to examine this with a view to recommending changes in port practices that would lower the risk of invasion by introduced species.

Biological Control

The CRIMP advisory committee recommended that in the medium to long term, significant centre resources should be allocated to assess the feasibility of developing biological control techniques for established pest species. CRIMP is currently recruiting specialist staff to develop this program, which is expected to draw heavily of the extensive experience of other CSIRO Divisions that work on the integrated pest management of terrestrial pests. Initial efforts will focus on natural parasites and pathogens, with the intent of moving to transgenic technology only if necessary. Work on transgenic technology is underway in several CSIRO Divisions, but the ethical problems associated with this approach (Goodman, 1993) and the practical difficulties involved in adapting the technology to marine organisms warrant a detailed search for natural parasites first.

While awaiting appointment of key staff, CRIMP has commenced several information gathering projects. Field teams have been commissioned to examine native populations of the northern Pacific seastar, *Asterias amurensis*, in Russia and Japan to identify potential biological control agents. At this stage, the most likely candidates are eulimid gastropods and ascothoracidan barnacles, both parasitic castrators. A small project to assess the feasibility of mass rearing marine parasites for release has also been commissioned, as part of a collaborative study with Armand Kuris's laboratory at the University of California on the potential for biological control of the European shore crab, *Carcinus maenas*. We will also be shortly having discussions with specialist parasitologists working on several, possibly relevant groups, with a view to funding projects relevant to the biological control initiative. In Australia, monitoring programs are being put in place for the two species that are likely first targets for attempted biological control (*Carcinus* and *Asterias*) so that adequate baseline information is available on the population dynamics of these species against which the impacts of the biological control agent can be assessed.

It is difficult to predict the time course of the biological control project, given vast uncertainties in everything from the availability of parasites to the likelihood that they can be reared in captivity. Optimistically, CRIMP hopes to undertake trial releases of parasites in 3-4 years, with full scale release 1-2 years later, following detailed impact assessments.

References

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Table 1. Known introduced marine species in Australian waters; their possible origin, likely mode of introduction, and current Australian status.

Taxon	Species	Possible origin	Mode of Introduction	Australian status
ANIMALS				
Coelenterata				
Hydrozoa				
	Bougainville ramosa (hydroid)	N. Hemisphere	hull	?
Annelida				
Polychaeta				
	Hydroides norvegica (serpulid)	Europe	ballast; hull	?
	Mercierella enigmatica (serpulid)	India	ballast?; hull	?
	Boccardia proboscidea (spionid)	Japan/NE. Pacific	ballast; hull	abundant
	Polydora cilliata (spionid)	Europe	?	?
	Pseudopolydora paucibranchiata (spionid)	Japan/NE. Pacific/NZ	ballast; hull	?
	Sabella spallanzanii (giant fan worm) [2]	Mediterranean	ballast	abundant; pest
Mollusca				
Gastropoda				
	Maoricolpus roseus (screw shell)	NZ	with oysters	abundant
	Zeacumantis subcarinatus (screw shell)	NZ	?	?
	Aeolidiella indica (sea slug)	widespread	ballast; hull	common
	Janolus hyalinus (sea slug)	Europe	hull	?
	Okenia plana (sea slug)	Japan	hull	?
	Polycera capensis (sea slug)	California	hull	?
	Godiva quadricolor (sea slug)	S. Africa	hull?	?
	Thecacera pennigera (sea slug)	?	hull	?
Bivalvia				
	Crassostrea gigas (Pacific oyster)	Japan	deliberate	commercial; pest?
	Neilo australis (clam)	NZ	with oysters	common
	Ostrea lutaria (NZ mud oyster)	NZ	deliberate	?
	Paphirus largellierti (clam)	NZ	with oysters	?
	Perna canaliculus (NZ green mussel) [1]	NZ	with oysters; hull?	
	Musculista senhousia (Asian mussel)	Pacific/Asia	hull; ballast	common
	Theora lubrica (semelid)	Pacific/Asia	ballast	?
Polyplacophora				
	Amaurochiton glaucus (chiton)	NZ	with oysters	?
Crustacea				
Mysidacea				
	Neomysis japonica (mysid shrimp)	Japan	ballast	?
Tanaidacea				
	Tanais dulongi (tanaid)	Europe	ballast	common
Isopoda				
	Cirolana hardfordi (isopod)	USA	hull	?
	Eurylana arcuata (isopod)	NZ/Chile	hull; ballast	?
	Paracerceis sculpta (isopod)	USA/S. America	hull	?
	Paradella dianae (isopod)	USA/S. America	hull	?
	Sphaeroma serratum (isopod)	widespread	hull	?
	Sphaeroma walkeri (isopod)	Indian Ocean	hull	?
Cirripedia				
	Balanus improvisus (barnacle)	Atlantic	hull	?
	Megabalanus rosea (barnacle)	Japan	hull?	?
	Megabalanus tintinnabulum (barnacle)	cosmopolitan	hull	?
	Notomegabalanus algicola (barnacle)	S. Africa	hull	?
Decapoda				
	Cancer novaezelandiae (crab) [1]	NZ	with oysters	common
	Carcinus maenas (European shore crab) [2]	Europe	hull?; ballast?	common; pest

Table 1 continued

Halicarcinus innominatus (crab)	NZ	with oysters; hull	?
Pyromaia tuberculata (crab)	E. Pacific	ballast	?
Palaemon macrodactylus (Japanese shrimp)	N. Pacific	?	common?
Bryozoa			
Anguinella palmata	Atlantic	hull	?
Bugula flabellata	Atlantic/Mediterranean	hull	?
Conopeum tubigerum	Atlantic	hull	?
Schizoporella unicornis	Japan	hull?	?
Watersipora arcuata	Mexico	hull	?
Echinodermata			
Asteroidea			
Asterias amurensis (northern Pacific seastar) [2]	Japan	ballast	abundant; pest
Astrostole scabra (seastar) [1]	NZ	?	common
Patiriella regularis (seastar)	NZ	with oysters	common
Chordata			
Ascidiacea			
Molgula manhattensis (ascidian)	N. Atlantic	hull	?
Styela clava (ascidian)	NW. Pacific/Europe	hull	?
Styela plicata (ascidian)	widespread	hull	?
Pisces			
Latelabrax japonicus (Japanese sea bass)	Japan	ballast	established
Triso dermopterus	W.-Equat. Pacific	ballast	established
Sparidenrax hasta (Sobaity sea bream)	Arabian Gulf	ballast	?
Tridentiger trigonocephalus (striped goby)	W.-Equat. Pacific	ballast	established
Acanthogobolus flavimanus (yellowfin goby)	W.-Equat. Pacific	ballast	established
Fosterygion varium (blenny)	NZ	?	common
Oreochromis mossambicus (tilapia)	SE Asia	deliberate	common; pest?
Salmo salar (Atlantic salmon)	N. America	deliberate	commercial
Salmo trutta (brown trout)	UK	deliberate	common
Oncorhynchus mykiss (rainbow trout)	NZ (California)	deliberate	commercial
PLANTS			
Phycophyta			
Chlorophyceae			
Caulerpa filiformis	S. Africa	hull?	abundant
Caulerpa taxifolia [1]	Atlantic/Indo Pacific	hull?	abundant
Dinophyceae			
Gymnodinium catenatum (dinoflagellate) [2]	Japan?	ballast	abundant; pest
Alexandrium minutum (dinoflagellate) [1, 2]	Mediterranean?	ballast?	abundant; pest
Alexandrium catanella (dinoflagellate) [1, 2]	Japan?	ballast?	abundant; pest
Rhodophyceae			
Arthrocladia villosa	N. hemisphere	?	?
Sperococcus compressus	N. hemisphere	?	?
Antithamnionella spirographidis	N. hemisphere	?	?
Polysiphonia brodiaei	N. hemisphere	?	?
Polysiphonia pungens	N. hemisphere	?	?
Phaeophyceae			
Undaria pinnatifida ("wakame") [2]	Japan	ballast; hull?	abundant; pest
Discosporangium mesarthrocarpum	Mediterranean	?	?
Spacella subtilissima	Mediterranean	?	?
Zosterocarpus spp.	Mediterranean	?	?

Notes:

1 Introduced status uncertain; possibly an Australian endemic.

2 IABWMAC target pest species