The Global Invasive Species Programme

BEST PRACTICE FOR THE MANAGEMENT OF INTRODUCED MARINE PESTS

A REVIEW

Prepared for GISP by
URS Australia Pty. Ltd.

Acknowledgements

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This document is the result of a review undertaken by a specialist team from URS Australia on behalf of GISP.

Prepared by: **Robert Hilliard**
Reviewed by: **John Polglaze**
Authorised by: **Ian LeProvost**

LIST OF FIGURES

LIST OF APPENDICES

GLOSSARY OF ACRONYMS

ANS	Aquatic nuisance species
ANVISA	Agência Nacional de Vigilância Sanitária (Brazil's National Agency for Sanitary Surveillance)
ANZFA	Australian and New Zealand Food Authority
APEC	Asia Pacific Economic Cooperation forum (Australia, Canada, Chile, China, Indonesia, Japan, Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, Philippines, Peru, Russia, Singapore, Thailand, United States, Vietnam).
AQIS	Australian Quarantine Inspection Service
BW	Ballast water
BWC	Ballast Water Convention (IMO *Convention for the Control and Management of Ships' Ballast Water and Sediments*)
BWM	Ballast water management
BWRA	Ballast water risk assessment
BWRF	Ballast Water Reporting Form (a standard IMO BWRF is shown in Appendix F).
CBD	Convention on Biological Diversity
CCA	Solution of copper, chrome and/or arsenic salts used in timber treatments
CRIMP	Centre for Research on Introduced Marine Pests (now part of CSIRO Marine Research, Hobart, Tasmania)
CIESM	International Commission for the Scientific Exploration of the Mediterranean
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DDSS	Dry-docking support strips
DEH	Commonwealth Department of the Environment and Heritage (formerly Environment Australia)
DPIF	Department of Primary Industry and Fisheries (NTG, Australia)
DSS	Decision support system (implemented to facilitate risk based management)
DSTO	Defence Science and Technology Organisation (Australia)
DWT	A ship's deadweight tonnage (typically reported in metric tonnes)
EPA	Environmental Protection Authority
EPHC	Environment Protection and Heritage Council (of Australia)
FAO	Food and Agriculture Organisation (a United Nations organisation)
GEF	Global Environment Facility (funded by the World Bank)
GIS	Geographic information system
GISP	Global Invasive Species Programme
GloBallast	The GEF/UNDP/IMO Global Ballast Water Management Programme
GMO	Genetically Modified Organism
HMS	Harmful marine species
IAS	Invasive alien species
IBSS	Institute of Biology of the Southern Seas, Ukraine Academy of Sciences
ICES	International Council for the Exploration of the Sea
IFREMER	Institut Francais de Recherche pour L'Exploitation de al Mer
IMO	International Maritime Organization (a United Nations organisation)
IPN	Infectious pancreatic necrosis
ISA	Infectious salmonid anaemia
ISSG	Invasive Species Specialist Group (of IUCN's Species Survival Commission)
IUCN	The World Nature Conservation Union
LAT	Lowest Astronomical Tide

MAF	Ministry of Agriculture and Forestry (New Zealand)
MEPC	Marine Environment Protection Committee (of the IMO)
MSDS	Material Safety Data Sheets
NBI	National Botanical Institute (South Africa)
NDPSC	National Drugs and Poisoning Scheduling Committee (Australia)
NEMISIS	National Estuarine & Marine Invasive Species Information System (a database of introduced aquatic species managed by SERC)
NICNAS	National Industrial Chemicals Notification and Assessment Scheme (Australia)
NIMPIS	National Introduced Marine Pests Information System (managed by CSIRO)
NIO	National Institute of Oceanography (India)
NIS	Non-indigenous species (non-native species)
NIWA	National Institute of Water & Atmospheric Research Ltd (New Zealand)
NOHSC	National Occupational Health and Safety Commission (Australia)
NRS	National Residue Survey (Australia)
NTG	Northern Territory Government (Australia)
NZ	New Zealand
OH&S	Occupational Health and Safety
PAC	Polyhydroxy aluminium chloride (a surfactant)
PBBS	Port Biological Baseline Survey (that targets introduced species)
PCP	Pentachlorophenol (usually as sodium pentochlorophenate)
PIC	Prior Informed Consent
QEPA	Queensland Environmental Protection Agency (Australia)
QRA	Quantified Risk Assessment
SAP	(Regional) Strategic Action Plan
SCC	Standing Committee on Conservation (Australia)
SCFA	Standing Committee on Fisheries and Aquaculture (Australia)
SERC	Smithsonian Environmental Research Center (Washington DC, United States)
SUSDP	Standard for Uniform Schedule of Drugs and Poisons (Australia)
TBT	Tributyltin
TGA	Therapeutic Goods Administration (Australia)
WHO	World Health Organisation (a United Nations organisation)

1. INTRODUCTION

1.1 BACKGROUND AND SCOPE

The Secretariat of the Global Invasive Species Programme (GISP) commissioned URS Australia Pty Ltd (URS) on 1 December 2003 to compile and briefly review literature and material available globally on best practice for the management of introduced marine pests. To help achieve this goal, URS consulted with a range of bioinvasion managers and researchers to locate recent published and non-published information from various published, non-published and internet sources.

The desktop compilation and mini-review of existing information is required by GISP as the first step in its plan to produce a toolkit specifically for the prevention and management of invasive marine species. The scope and objectives of the initial step have been as follows:

1. Provide a compilation of all relevant literature and material available globally, rather than an in-depth analysis of the pros and cons of different approaches.
2. Cover all possible pathways/vectors of ‘invasive alien species’ (IAS) in the marine environment with a focus on actual rather than hypothetical cases, including intentional and unintentional introduction pathways, plus natural range expansions resulting from climate change and other human activities.
3. Include case studies demonstrating ecological, economic and social impacts (such as the *Caulerpa taxifolia* ‘aquarium strain’ in the Mediterranean and elsewhere), best practice manuals (e.g. the Rapid Response Toolbox in Australia’s National Introduced Marine Pest Information System), information on relevant technologies (especially new developments and voluntary guidelines such as the IMO guidelines on ballast water management), and recent regulations at sub-national, national and international levels (e.g. the New Zealand *Biosecurity Act* 1993).
4. Cover all aspects of IAS management, i.e. from prevention through early warning and surveillance systems, eradication, containment and monitoring, management and control.
5. Make the maximum possible use of web-searches and appropriate mailing lists within the time constraints of the study to provide the broadest possible coverage of reports, many of which are grey literature.

A review summarizing the collated material was also needed, as well as lists of the literature, websites, manuals, experts etc, reviewed or consulted. This included compiling a bibliographic appendix to list the collated published and grey literature references, species databases, toolkit materials, web-based information sources, and the home page or contact address of all national, regional, international and multilateral organizations and agencies relevant to marine pest management. Because many terms used in bioinvasion management are by no means clear cut and often confusing[1], the review also provides a comprehensive glossary (Section 2). The text has tried to avoid unnecessary jargon and highly technical terms wherever possible, to assist international readers whose first language may not be English.

[1] see Carlton (2002) for more on this topic (in Chapter 2 of *Invasive Aquatic Species of Europe* [eds E Leppäkoski, S Gollasch & S Olenin], Kluwer Academic Publishers, 2002, pages 7-20).

1.2 APPROACH AND METHODS

The overall approach was to widen and up-date the literature, database sources and case histories provided in GISP's previous publication on invasive species management (Wittenberg & Cock 2001), with the focus on marine taxa. A wide geographic spread of workers was messaged by email or telephone to solicit information and material allowing preparation of case histories. The short project schedule and its seasonal timing constrained our ability to solicit and receive contributions from workers around the world for updating old and/or providing new case studies (many were away or had taken early Christmas/New Year leave). Nevertheless information was sourced from researchers/administrators in the pilot countries of the Global Ballast Water Programme (Brazil, China, India, Iran, South Africa, Ukraine) plus workers in Argentina, Australia, Canada, Croatia, Germany, Israel, Japan, Netherlands, New Zealand, Norway, Slovenia, Sweden, the United States and United Kingdom.

Based on the materials and responses obtained in time for this report, over fifteen cases covering a range of geographic regions, invasive species and management outcomes have been included. Although the brief is focussed on marine species, euryhaline freshwater cases have been included since several European seas, American embayments and internal 'seaways' (including the Bohai Sea in northeast China) contain species in this category which have been spread via marine shipping – including the Asian golden mussel to South America and the many NIS exchanged between the Ponto-Caspian and North America (e.g. Leppäkoski & Olenin 2000). It is also worth noting the ICES (1999) definition of a marine species, which is "*any aquatic species that does not spend its entire life-cycle in fresh water*".

Although bioterrorism is a potential vector for transmission of harmful aquatic organisms, it is not covered in this report as the species most likely involved would be non-marine taxa for disrupting water supplies or agricultural resources.

1.3 STUDY TEAM AND ACKNOWLEDGEMENTS

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2. TERMS AND DEFINITIONS

2.1 SOURCE AND NATURE OF CONFUSING TERMS

"*The less a science has advanced, the more its terminology tends to rest upon uncritical assumptions of mutual understanding*" (from Quine 1946, as quoted by Carlton 2002).

The understanding, modelling and management of marine species invasions is an immature, emerging science and its terminology continues to evolve and change. Presently there is no convenient, widely-referenced glossary of terms that provides an integrated set of consistent, logical definitions based on fully understood processes. Most primary invasions by aquatic species are international, and successful efforts to curb and combat them require the mutual understanding and willing cooperation of many marine scientists, advisers, officials and politicians whose first language is not English. Use of apparently interchangeable but often ambivalent and confusing terms can therefore hinder understanding and progress.

The following text reviews terms defined, used or discussed in a range of publications and reports, including Carlton (1985, 1987, 1996), OTA (1993), Cohen & Carlton (1995), Hilliard *et al* (1997), Hilliard (1999), Hutchings *et al* (2002), Ruiz *et al* (1997, 2000), Williamson *et al*. (2002), Clarke *et al* (2003), Russell *et al* (2003), URS-Meridian (2004) plus government committee papers, international convention documents and NGO material.

'Non-native species' and 'non-indigenous species' (NIS) are more precise and preferable to vernacular and ambiguous terms such as adventive, alien, exotic, feral[2], foreign, invasive, ornamental or weedy species, which can conjure unpredictable misinterpretations and cultural nuances (Section 2.3). Warnings placed in documents destined for international circulation such as "*It should also be noted that several terms are used interchangeably. These include: mariculture and aquaculture; invasive alien species and introduced pests; exotic, alien and introduced. Acknowledgment of this is important for clarity of this report.*" (Williamson *et al* 2002) highlight the problem but unfortunately are rare and do not resolve the issue.

A 'cryptogenic species' is simply "*neither demonstratively native nor introduced*" (Cohen & Carlton 1995, Carlton 1996). Many of the widespread and so-called 'cosmopolitan' marine species are cryptogenic because their original, natural distribution has been blurred by centuries of transfers via sailing ships, canals, barges, aquaculture, etc. In fact in some regions many historical introductions had been assumed part of the native marine community until recent studies invoked doubt. Examples include several common foulers and wood-borers, such as the infamous bivalve 'shipworm' (*Teredo navalis*), the ship or striped barnacle (*Balanus amphitrite*), oysters and both blue (*Mytilus*) and brown (*Perna*) mussel complexes (e.g. Carlton 1999, Leppäkoski *et al* 2002, Zaitsev & Öztürk 2001, Dr F. Fernandes, pers comm.).

The terms 'introduction' and 'introduced species' still cause confusion owing to the often terse and ambiguous definitions promulgated by government agencies, tasking committees, international and national organisations, research bodies and academics. Examples include:

ICES (1994, 1999): '*An introduced species is any species accidentally or intentionally transported and released by humans into an area outside its present range'*.

Convention on Biological Diversity (CBD): '*"Introduction" refers to the movement by human agency, indirect or direct, of an alien species outside of its natural range (past or present)*' and *"Alien species"* (sic) *refers to a species, subspecies or lower taxon, introduced outside its*

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2 A feral marine species may be defined as a NIS originally imported for the aquaculture or aquarium trade, and then escaped to establish a self-maintaining population in the wild. This provides the same meaning used for feral (previously-domesticated) terrestrial animals (many aquaculture and aquarium species undergo some form of selection for improved tank husbandry, growth etc).

natural past or present distribution; including any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce'.

APEC (Williamson *et al* 2002): 'A*n introduction/translocation is the human-assisted movement of an animal to an area outside its natural range*' and '*An introduced species is a marine species that's movement has been assisted by human activities to an area outside its range'*.

US Aquatic Nuisance Species (ANS) Executive Order 13112 (Clinton 1999): '*"Introduction" means the intentional or unintentional escape, release, dissemination, or placement of a species into an ecosystem as a result of human activity*'.

The ICES and CBD definitions ignore self-mediated range expansions following removal of barriers (via canals, channelised waterways, anthropogenic changes to salinity gradients and regional/local climate, etc). Canal-mediated dispersal of planktonic forms (including the propagules of sessile benthic species) and migratory species into regions beyond their native range cause *bona fide* introductions. Of the two APEC definitions, the first barely implies the existence of indirect mechanisms and both are inconsistent in other respects. The definition in the US ANS Executive Order covers all mechanisms enabling an introduction but fails to clarify what "ecosystem" with respect to the species' native or current introduced range.

The above definitions do not clarify if the term 'introduced species' should apply equally to ephemeral populations (i.e. short-lived presence of pioneering individuals or founder groups) as well as established populations. Transitory appearances of putative but ultimately unsuccessful founder populations are well documented, including instances where pioneering individuals may be detected and reported but which:

- die out within a few weeks, months or years; or
- maintain a precarious foothold within a modified or artificial habitat, sometimes assisted by repeated translocations of new individuals, e.g. in a naval dockyard, harbour basin, lock-gate marina or degraded parts of an urbanised estuary (Kott, in Furlani 1996).

Some marine introductions have involved repeated inoculations to maintain a sporadic or continuous presence, while others may form founder population/s which remain small and restricted for several years or decades before alterations to genetic or environmental factors allow expansion and spread (e.g. Cohen & Carlton 1995, Hilliard *et al* 1997, Ruiz *et al* 2000, Leppäkoski *et al* 2002). Thus whether or not a group of pioneering organisms manages to survive, grow, reproduce and recruit to produce a self-maintaining founder population, and whether this in turn may generate a larger and more viable population that survives extreme natural events and persists over the long term, depends on a chain of circumstances and events involving a complex interplay of genetic, physical and biological factors.

If they are to be useful, terms such as 'introduced species' need to recognise key steps along the path between the initial NIS appearance and its ultimate fate. Some definitions recognise this need, placing an 'introduced species' beyond the first tenuous steps of the introduction process. For example, '*an introduced species is one which, through direct or indirect human activity, has established a self-reproducing population in a natural or semi-natural habitat outside its native range*'. Ruiz *et al*. (2000) have also identified both '<u>failed</u>' and '<u>extinct introduced species</u>': '*Failed introductions are species that were reported but for which there is no evidence of establishment. In contrast, extinct introductions survived and reproduced for many years before disappearing*'.

Cohen & Carlton (1995) defined an '<u>established</u>' NIS as: "*an introduced species that is present and reproducing in the wild, and whose numbers, age-structure, distribution and persistence over time suggest they will continue to be present - barring eradication efforts or a major natural catastrophic event*". The end clause has been questioned, particularly for regions where catastrophic natural events such as a major flood, severe winter, drought or cyclone are not rare (Hilliard *et al* 1997). For their analysis of aquatic species invasions in North America, Ruiz *et al* (2000) classified 'established populations' as: '*documented as present and reproducing within the last 30 years. Multiple records were required for a species to be considered established. Furthermore, for species detected in the past 10 years, occurrence was necessary in at least two occasions or in two consecutive years'.*

It is worth noting the above concepts regarding established populations focus on the evidence of persistence and pay no attention to their capacity to spread. However the more a population spreads the more likely it will persist should adverse conditions occur. Since spreading is also a key facet of the invasion process, it seems appropriate to define an 'established NIS' as: '*an introduced species with a population documented as persisting in natural or semi-natural habitats for at least several years, including at least one climatic extrema, and whose current abundance, age-structure and distribution suggest it will continue to persist and be capable of spreading by natural or human-assisted means'.*

'Invasive' NIS form a subset of established introduced species, although increasing *ad hoc* use of this term during the 1990s to convey a sense of impact and urgency for virtually any introduction has diluted its scientific meaning (Carlton 2002). As noted by Hutchings *et al* (2002), invasive marine species often display the following traits:

- Widespread (= widely distributed and generally common across their native range and capable of generating major recruitment / settlement events);
- Generalist (= re. animals capable of securing and ingesting a wide range of food);
- Tolerant (= can withstand a relatively broad range of physical conditions including temperature and salinity, and often having a tough or quiescent stage well-adapted for dispersal and/or surviving extreme conditions respectively);
- Pioneering (= among the first to colonise or utilise disturbed or vacant habitats).

The definitions of invasive NIS in Clinton's (1999) ANS Executive Order ('*an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health'*) and by IUCN (2000; '*an alien species that becomes established in natural or semi-natural ecosystems or habitats, is an agent of change, and threatens native biological diversity*') are so terse they imply it is unnecessary to spread to cause harm. By invoking unclear and indistinct concepts, these definitions were also considered imprecise and problematic by Carlton (2002) who highlighted the problem of 'daily definitions' (sensu Bachrach; '*a major error in scientific method is the use of daily definitions*'; in Carlton 2002).

The more descriptive definition promulgated by the Oregon Invasive Species Council notes some invasive features but also focuses on how invasive species cause harm: *Invasive species are those plants, animals, and microbes not native to a region which, when introduced either accidentally or intentionally, out-compete native species for available resources, reproduce prolifically, and dominate regions and ecosystems. Because they often arrive in new areas unaccompanied by their native predators, invasive species can be difficult to control. Left unchecked, many invasives have the potential to transform entire ecosystems, as native species and those that depend on them for food, shelter and habitat disappear*. Similarly, the short definition of invasive in the CBD ('*an alien species whose introduction and/or spread threaten biological diversity*') acknowledges the role of spread but focuses on the threat of biodiversity loss, which is appropriate given the purpose of this convention.

The above definitions are policy oriented and ignore the key property of truly invasive species, i.e. their ability to spread with minimal human assistance through relatively undisturbed wild or semi-natural areas. The ability of marine NIS to colonise relatively undisturbed habitats and communities depends on their capacity to occupy unused niche space or else out-compete existing native taxa by superior means of growth, reproduction, dispersal, recruitment, fitness or survival (including a potentially high level of impunity to local predators, parasites and pathogens). More explicit scientific definitions of 'invasive' are available (e.g. Thomson 1991, Hilliard *et al* 1997, Ruiz *et al* 1997), such as: '*an introduced species with established population/s that tolerate a range of environmental conditions, possess efficient self-dispersal mechanisms, colonise wide geographical areas, form a common component of the habitats and communities into which they spread, and appear capable of exponential expansion'*.

Invasive marine species which develop dense populations can overwhelm and displace native taxa via predation, shading, smothering, altering substrates and/or diverting food chains via excessive filtering or grazing. While policy oriented definitions of the CBD, IUCN and GISP adopt the precautionary 'guilty until proven' principle to highlight this biodiversity threat, they provide no hint about what invasive species are or that they can have neutral or beneficial outcomes in both terrestrial and aquatic realms. By directly equating invasive with ecological harm, they imply it is unnecessary to differentiate or label such taxa as 'harmful'.

While the majority of invasions cause unwanted outcomes, some marine NIS have spread relatively rapidly without significant demonstrable harm to native biodiversity, ecosystems or fisheries, particularly in locations containing unfilled niches (Eltonian or 'ecological' space). Such cases include outcomes which have been neutral and/or outweighed by serendipitous benefits for reasons discussed later (Section 2.4.2). Examples range from the serendipitous effect of the *Beroe* comb jelly in the Black Sea[3] to many of the marine fish and invertebrate introductions in the Eastern Mediterranean (Section 3.2.1), and the Caribbean barnacle in the Hawaiian Islands (*Chthamalus proteus*; Zabin & Hadfield 2002). There are also cases in Asia, Europe, New Zealand and the Americas where unintentional marine introductions have become significant components of local commercial catches or cultured stocks without appearing to have markedly reduced or degraded native fishery stocks or communities[4].

As noted by Carlton (2002), the effects of invasive marine NIS on aquatic native biodiversity, ecosystem functioning and economic societal activities cannot readily be divided into 'harmless' and 'harmful' as they fall on '*a long sliding scale of modifications, alterations and adjustments'*. Carlton (2002) also noted that some workers have argued that invasive species which meet a 'rapid spread' criterion must, *ipso facto*, be exerting unwanted ecological impacts, and therefore all invasive species should be placed under the 'harmful' umbrella. Abandoning the need to qualify 'invasive' with 'harmful' is not useful for marine invasion managers and their scientist advisers who must make pragmatic decisions regarding the allocation of management and response funds from risk assessments results. It therefore seems appropriate to allow such divisions and qualifications, at least for the time being.

Thus invasive NIS which threaten or cause demonstrable adverse impacts as a result of their sheer density or other noxious traits warrant appropriate labelling, and this marks a split of the CBD-IUCN-GISP terminology from that commonly used around the world for managing marine NIS.

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3 The unintentional introduction and subsequent invasion of the comb jelly *Beroe ovata* in the Black Sea, a natural predator of *Memniopsis leidyi* markedly reduced the density and impacts of this harmful invader (Section 4.10).

4 'Plagues' and invasions which damage coral reefs, disrupt fisheries and reduce tourism values can be caused by native species in their natural ranges (e.g. *Drupella* snails, sea urchins, Crown of Thorns starfish, Amur sea stars [*Asterias. amurensis*]). Natural invasions are not uncommon in the marine realm where recruitment success and population density can vary widely from year to year owing to the inherent vagaries of supply-side ecology and nutrient regimes in dynamic hydrological environments. The frequency and severity of some outbreaks in the 1980s-1990s are thought to be driven by nutrient fluxes exacerbated by human activities.

Three widely-used and essentially interchangeable terms for defining 'harmful' marine NIS are widely used by agencies and organisations charged with managing aquatic introductions. These are:

- Aquatic nuisance species (ANS) - USA/Canada
- Harmful marine species (HMS) – International Maritime Organization (IMO)
- Marine pest - Australia/New Zealand/UK

As with 'invasive alien species', they are terms adopted for the guidelines, lists and statues that were compiled for the emerging policies of governments and international organisations during the late 1980s and 1990s. Each term was coined according to agency drafting preferences relating to awareness-building and mass-media objectives, with no clearly defined scientific basis. As noted by Carlton (2002): "*the concepts and thus words used to describe non-native species vary among countries and among scientists, and in the near future show no clear indication of achieving either intra-national or international uniformity (or understanding)*". Unless this is recognised by students and newcomers, they may wonder if the different terms represent actual or perceived differences in the type or scale of impact on diversity, ecosystem structure and function, economies or social values.

In line with Carlton's (2002) plea regarding the need to clarify the terminology of the marine invasion process, the above terms should be regarded as fully interchangeable and may be placed under a more explicit umbrella definition. For known 'harmful NIS', an appropriate scientific definition would be: "*Any invasive species which has demonstrably:*

- *reduced native biodiversity via infection, predation, competition, habitat alteration or diverting food-chains;*
- *infected, parasitised or otherwise directly or indirectly damaged an important fishery or aquaculture stock;*
- *caused gross fouling to hulls, intakes, jetty piles, navigation aids, mariculture nets, etc;*
- *increased public health risk by direct infection or indirectly by the production of toxins that may also disrupt aquaculture operations; and/or has*
- *degraded locally important public amenity or aesthetic values.*

In the case of suspected but unproven harmful invasive species, terms such as 'suspected harmful NIS', 'risk species' 'potential marine pest' have been used for inductive reviews of available information to identify potential 'next pests' (e.g. Hayes *et al* 2002, Clarke *et al* 2003, Russell *et al* 2003, URS-Meridian 2004). Such terms are useful whenever feared or predicted impacts await confirmatory field evidence, a refereed publication or expert committee report.

2.2 VECTORS, ROUTES AND PATHWAYS

The meaning of these terms continues to differ among agencies and countries. Many quarantine managers and invasion workers use 'vector' to describe any means, agent or mechanism causing a species translocation or spread, and 'pathway' to refer to the particular geographic route/s taken by each vector.

In contrast, the US National Invasive Species Council (NISC) definitions restrict the meaning of 'vector' to its original use within the realm of human and agricultural disease. Thus NISC defined vectors as "*biological pathways for a disease or parasite (i.e. an organism that transmits pathogens to various hosts), and not completely synonymous with the much broader definition of a pathway*". NISC therefore asserted that 'pathways' includes natural agents (i.e.

winds, currents or other dispersal mechanisms used by particular species) as well as intentional and unintentional human-assisted 'pathways'. This approach is confusing and this review maintains the more straightforward former view, in which the vector comprises any agent or physical mechanism that facilitates disjunct dispersal or spread, and the pathway represents the particular geographic route or corridor taken, or formed by, that vector.

In line with the original use of vector (as a medical term for the agents which introduce pathogens and parasites to their hosts), inoculation is frequently used to describe the release, discharge, spawning or dislodgement of viable marine organisms into a new environment (e.g. Hilliard *et al* 1997, Hayes 1997, Hewitt & Hayes 2002, Ruiz 2002). The inoculation concept is appropriate because outcomes (NIS 'infection' of ports, coasts and inland waters) depend on the strength and viability of the inoculum, plus the degree of exposure to inoculations and intrinsic 'health' of the receiving 'host' environment (Section 2.4).

Inoculations of NIS must contain sufficient numbers and/or occur in sufficient frequencies to provide more than a negligible chance of initiating a founder population. Although it is theoretically possible for a single release of two individuals (or one small colony) to eventually generate a viable population, the chances are vanishingly small for the vast majority of aquatic species and circumstances (e.g. Boero, in CIESM 2002). Probably the most plausible exception to this rule-of-thumb is the transfer of a handful of mature adults into a semi-enclosed, quiescent area such as a poorly flushed harbour or coastal lagoon - particularly if the adults are a highly regenerative plant or fecund fouling species, and the basin contains vacant habitat / niche space. With appropriate water quality and spawning cues a few adults may release thousands of gametes, causing a successful settlement (e.g. *Mytilopsis* mussels in Darwin marinas, *Chthamalus proteus* in Hawaiian harbours; *Hydroides sanctaecrucis* in Cairns harbour; Coles & Eldredge 2002, Hutchings *et al* 2002, Section 4.7).

Evaluating NIS vectors and their routes is an integral part of the risk management approach to bioinvasions (Section 2.4). The pathways can be divided into primary and secondary categories. Primary pathways refer to those vectors and routes which introduce species to previously inaccessible regions or provinces owing to their location beyond major oceanic, landmass or climatic barriers (i.e. trans-oceanic and intercontinental pathways), while secondary pathways help spread and disperse NIS between points within or between neighboring regions (e.g. the routes used by domestic and local 'hub' shipping, fishing vessels or trailered boats). Thus 'secondary' pathways include all 'within-region' activities and circumstances which can facilitate the local spread of a NIS after its founder population has established. These secondary range expansions may start quickly or require several years or even decades before eventual removal of some internal or external constraining factor/s provides the impetus (e.g. genetic acclimation, or an improved waterway, new trading route, removal of a weir or barrage or favourable shift in temperature/salinity regime, etc).

The rates of marine introductions and spread are inherently variable but there is little doubt they have been increasing since the 1960s (e.g. Carlton 1985, 1987, 1999, Cohen & Carlton 1995, Ruiz *et al* 1997, 2000). Arguments that all marine species capable of introduction have now established in all possible areas owing to the range of historically unmanaged vectors and routes (particularly. hull fouling, solid ballast, water ballast and aquaculture) have been widely rejected. There are many cases where species must have been translocated for many decades but did not establish until recent times, and these have been related to concept of increased 'propagule pressure' (e.g. Ruiz *et al* 2000, Ruiz 2002). Propagule pressure increases whenever improvements to the vector or its route cause more frequent, larger and/or fitter inocula (e.g. larger and faster ships, larger and cleaner segregated ballast tanks, shorter canal-assisted voyages, improved ballast tank water quality, etc).

Other factors explaining the rise in marine introduction and spread rates since the 1960s are the anthropogenic changes that have made many aquatic receiving environments more ‘invader friendly’. As described in Section 2.4, these changes include increased amounts of disturbed, artificial and/or eutrophic habitats, plus cases where either diversion of freshwater discharges to public supply/irrigation schemes, river water ionisation from industrial outfalls and urban run-off and/or regional climate change, have reduced the incidence of low salinity and temperature extrema (e.g. Zaitsev & Öztürk 2001, Leppäkoski *et al* 2002, CIESM 2002).

Island states and large countries which possess complete and relatively isolated coastal bioregions due to sheer distance, oceanic currents or other barriers, are in a position to take effective unilateral measures for managing both primary and secondary pathways (e.g. the Pacific Island states plus much of Australia, Brazil, Canada, Chile, New Zealand, South Africa and United States). In contrast, since most European, Asian and Central American nations share regional seas and/or major river systems (as do several South American countries), these countries must engage in coordinated multilateral efforts with their regional neighbours to achieve a similar level of efficacy.

In summary, there are many international and domestic transport and trade factors which have increased the frequency, size and health of marine inocula over the past 40 years, while a suite of other factors linked to economic coastal and waterway development have increased their chances of survival and acclimation in many new environments. Local selection pressures operating on NIS founder populations may also help their offspring retain or gain more pre-adaptations facilitating better chances of further translocation than their native range brethren.

2.3 SUMMARY DEFINITIONS

Many terms used in marine bioinvasion management are straightforward. Together with those addressed above, they can be summarily defined as follows:

Advection	Horizontal and vertical dispersal of organisms, propagules, particles, heat etc, by the movement of oceanic, coastal, estuary or riverine water currents.
Algicide	A substance or preparation used for destroying algæ.
Alien species	Popular mass-media term for non-native species. Has multiple contemporary and potentially offensive cross-meanings (extraterrestrial, foreign, non-citizen, immigrant, different race, peculiar, dislikeable, unnaturalised, weird).
Allee effect	Describes a scenario in which populations at low numbers can shrink due to a positive relationship between population growth rate and density. It explains why small, low density populations may experience increased extinction risk due to inadequate population growth.
Anthropogenic	Directly or indirectly caused by any type of human activity.
Aquaculture	Farming of aquatic organisms - typically involving interventions in the rearing process to enhance production and growth, such as stocking, feeding, disease/predator protection, etc. Implies individual or corporate ownership of the farmed stock (www.fao.org/docrep/t8582e/t8582e03.htm).
Aquatic species	Any organism which spends all or significant parts of its lifecycle in fresh, brackish or marine waters.
Aquatic nuisance species	Defined in the US NANSPC Act 1990 as: “…a nonindigenous species that threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters”. Has same meaning as *Harmful marine species* and *Marine pest*.
Ballast water	Any water and associated sediment used to manipulate the trim and stability

	of any vessel (including modern ocean racing yachts).
Ballast Water Convention	The IMO's *Convention for the Control and Management of Ships' Ballast Water and Sediments* (February 2004).
Baseline port survey	A biological survey aimed at finding and identifying all introduced marine species that may be present in a port (see Targeted port survey).
Benthic	Relating to, or inhabiting, the seabed.
Bilges, bilge spaces	The lowest internal portions of a vessel's hull.
Bilge water	Any water and other liquids that accumulate in the bilge spaces.
Biocide	A substance or preparation used for destroying living species by direct or indirect chemical means
Biodiversity	Biodiversity is the sum total of the variety of life and its interactions. Can be subdivided into genetic diversity, species diversity and ecological/ ecosystem diversity.
Biofouling	Aquatic organisms attached or nestling on or in a hull, including the internal seawater pipe work, anchor well, cable locker, bilges, etc.
Bioinvasion	A broad term which includes natural range expansions as well as the spread of an Invasive species.
Biological control	Control of pests and weeds by another organism (insect, bacteria, virus etc), by a biological product (hormone), or by genetic or sterility manipulations. Classic biological control uses a host-specific pathogen, parasite or predator obtained from the native range of the targeted pest.
Biological diversity	Same as *Biodiversity*.
Border	Any entry point into a recognised jurisdiction, such as a National, State or Economic border or other political boundary.
Bow or stern thruster	A propeller or water jet device set into the hull to improve manoeuvring or assist accurate positioning.
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 carbonyl diamide.
Carcinogen	A substance or agent that produces cancer.
Chemo-prophylaxis	Preventive treatment of an anticipated disease using chemicals.
Commensal organism	Any plant or animal that lives as a 'tenant' of other organisms but not at their expense (see *Parasite*). Commensals providing mild or essential benefits to their 'partner' organism form a *Symbiotic relationship*.
Control	The act of directing, regulating and checking actions and activities; the power or function of directing and regulating; command, domination.
Cost benefit analysis	A comparative analysis of all costs and benefits of undertaking different options, to help decide which actions provide the best value or most suitable outcome (may include the 'do nothing' option).
Cosmopolitan species	A wide-ranging species found in at least two ocean basins, often displaying a broad temperature tolerance. Often *Cryptogenic* in parts of its range.
Cryptogenic species	A species which is neither demonstratively native nor introduced in one or more regions. Includes many *Cosmopolitan* species.
Diquat	An organic quaternary compound with *herbicide* properties.
Disease	A clinical or sub-clinical infection by an aetiological agent (see *Pathogen*).
Domestic routes (shipping)	Intra-national routes (coastal and/or river voyages between domestic ports).
Endemic species	A species with a native distribution restricted to the bioregion/s of interest as a result of one of several biogeographical speciation mechanisms.

Endophyte	An organism growing inside a plant, such as an internal fungus.
Entrainment	Uptake of an aquatic species by a *Vector* such as *Ballast Water*.
Eradicate	To remove entirely, completely destroy, extirpate, get rid of.
Escapee	Any organism inadvertently allowed to pass through barriers designed to prevent their escape or release of propagules, such as escapees from public or private aquaria, research laboratories, etc.
Established introduction (see *Introduced species*)	A *Non-native species* that has established at least one self-sustaining viable population in the region of its introduction (abbreviated; see Section 2.1).
Exotic species	Ambiguous term for describing a *Non-native species*. Can invoke misunderstanding by implying a tropical origin and rareness. Originally used for spices, foods and plants with a striking smell, taste or coloration of tropical/subtropical origin (Exotica: excitingly different). See *Ornamental*.
Feral species	Any aquatic or terrestrial species which has established a population in the wild from previously domesticated or cultured populations (see Footnote 2).
Foreign routes (shipping)	International routes (voyages) between countries (see *Border*).
Fouling organism	Any plant or animal that attaches to natural and artificial substrates such as piers, navigation buoys, pilings or hulls. Includes crawling and nestling forms as well as seaweeds, hydroids, barnacles, mussels, bryozoans etc.
Genetically modified organisms (GMOs)	Organisms containing genetic material that has been altered by technologies such as isolation, modification or introduction of genes into living cells, or containing novel combinations of genetic material obtained via cell fusion.
Glyphosate	N-phosphonomethyl glycine ($C_3H_8NO_5P$) in solution or as the isopropylamine salt. A non-selective systemic herbicide that kills perennial weeds and an ingredient of several commercial weed killers.
Harmful marine species	Defined in the IMO *Ballast Water Convention* as: “Aquatic organisms or pathogens which, if introduced into the sea including estuaries, or into fresh water courses, may create hazards to the environment, human health, property or resources, impair biological diversity or interfere with other legitimate uses of such areas”. See *Aquatic Nuisance Species*; *Marine pest.*.
Hazard	A situation/activity that under certain conditions will cause harm. The likelihood of these conditions and magnitude of the harm produce a level of *Risk*.
Herbicide	A substance or preparation that is toxic to some or all plants and used to destroy unwanted vegetation.
Incursion	Unauthorised entrance or movement of a non-native species into a region or country where it is not already established. See *Interception*.
Indigenous (native) species	Naturally distributed within the region of interest, with a longterm presence extending into the pre-historic record.
Inoculation	Any *ballast water* discharge or transfer of biofouled material containing organisms not native to the receiving environment.
Integrated pest management	Long term application of a combination of chemical, physical, biological and/or habitat interventions to control the density or distribution of a pest.
Intentional introduction	Purposeful transfer or deliberate release of a non-indigenous species into a natural or semi-natural habitat located beyond its native range.
Interception	Detection of an non-native organism at a pre-border or border inspection point, quarantine facility or other type of biosecurity control location.
Introduced species	Any species whose movement into a region beyond its native range was directly or indirectly assisted by human activity, intentionally or otherwise. (includes species which make a self-mediated range expansion because of a new canal, waterway or anthropogenic climate change).
Invasive species	Any *introduced species* which spreads throughout a range of non-native natural or semi-natural habitats and ecosystems by its own and/or human-

	assisted means. Policy definitions and casual use of this term to describe virtually any introduction has diluted its meaning.
Management	Application of skills or care in the use, manipulation, treatment or control of things or people, or in the conduct of an activity, operation or enterprise.
Mariculture	A type of *Aquaculture* involving estuary or coastal water farming of any brackish or marine species.
Marine pest	Used frequently in Australian and NZ government publications and other literature to describe a noxious invasive marine species that threatens environmental, economic or social values (see *Aquatic Nuisance Species*; *Harmful Marine Species*).
Marine species	Any *Aquatic species* that does not spend its entire life-cycle in fresh water.
Mitigate/mitigation	To reduce, lessen, ameliorate or compensate negative effects and impacts.
Molluscide	Any preparation or substance used to kill molluscs.
Mutualism	see *Symbiotic Relationship*; *Commensal organism.*
Node	Any a point in a network where lines intersect or branch. Denotes ports or other places on vessel routes, including the points where voyages begin, end and cross the routes of other vessels.
Non-invasive species	An *Introduced species* that remains localised within a new environment and shows little propensity to spread despite several decades of opportunity.
Noxious species	Another term used in government legislation for listing unwanted species which are subject to regulations attempting to control their import or spread.
Ornamental species	Decorative plants and animals (including *GMOs*) with unusual or eye-catching features that are selectively bred, imported or genetically modified for display in gardens, parks, ponds or aquaria.
Organism	Any living unicellular, multicellular or viral entity capable of regeneration via self-repair, growth, replication or reproduction.
Parasite	Any fungus, plant, protozoan or metazoan animal that lives within (endoparasite) or on (ectoparasite) a living organism (host) and draws its nutriments directly from it. Typically reduces its host's fitness, growth, fertility and/or survivorship (c.f. *Commensal organism*).
Pathogen	Any protozoan, bacteria, virus, particle or other aetiological agent causing illness or *Disease*.
Pathway	The geographic *route* taken by one or more *vectors* from point A to point B.
Pelagic	Relating to, or inhabiting, the water column of open coastal waters or seas.
Pest	Any troublesome, noxious or destructive organism; a bane, 'curse' or 'plague' species (see *Aquatic Nuisance Species; Harmful marine species; Marine Pest; Noxious species*).
Pesticide	Any substance or preparation used for destroying a pest (typically associated with insects and rodents, with *herbicides* used for weed killers).
Phytohormone	Any hormone produced by algae or higher plants.
Piscicide	A substance or preparation used specifically to kill fish, often selected to have low or negligible effects on invertebrates or plants.
Predator	Any animal which hunts or traps individual animals to obtain food (unlike filter-feeders, krill-feeding baleen whales, etc).
Primary invasion	Initial establishment of an invasive marine species in a disjunct region (i.e. located beyond a land, ocean or temperature/salinity barrier).
Propagules	Dispersal agents of organisms, including spores, zygotes, cysts, seeds, larvae and self-regenerative tissue fragments.
Quarantined species/ organism	Any organism held in a confined or enclosed system designed to prevent its escape or release of associated disease agents or *Commensal organisms.*
Reservoir	An epidemiological term for NIS population/s which breed in uncontrolled

	locations to provide propagules or recruits that can spread to other areas.
Risk	The likelihood and magnitude of a harmful event (see *Hazard*).
Risk analysis	Evaluating a risk to determine what type and level of actions are worth taking to reduce the risk (often termed the '*Risk assessment*' in the US).
Risk assessment	Undertaking the various tasks required to determine the level of risk (often termed the '*Risk analysis*' in the US).
Risk management	The culture, organisational framework and activities which are directed towards identifying, evaluating and reducing risks.
Risk species	A species known or suspected to become a harmful species if introduced, based on documented outcomes or inductive evaluation of available evidence respectively.
Route	A geographic track or corridor followed by one or more *vectors* (see *Pathway*).
Saponin	Any of a large class of steroid glycosides obtained from plants and some animals. Many are toxic to fish (cause hæmolysis) and most are characterised by producing a soapy solution in water (e.g. Rotenone).
Sea chest	A substantial recess built into a vessel's hull covered by a grill, containing seawater intakes and designed to avoid cavitation and increase pumping efficiency to the cooling circuits. Located well below the waterline and typically near the engine room. Paired and multiple sea chests are common in commercial and fighting ships respectively.
Secondary invasion	Subsequent spread within a new region by the progeny of the initial founder population (see *Primary Invasion*).
Stowaway/Hitchhiker	Informal terms for any unobtrusive organism which is hidden from casual view by its location in niches, tanks, pipework, shells of dead animals, anchor wells, lockers, cargo or bilge spaces, containers, freight, luggage etc.
Surfactant	Any substance or preparation that lowers the surface tension of water, including detergents, dispersants, emulsifiers, wetting and foaming agents.
Symbiotic relationship	When a *Commensal organism* provides mild or essential benefits to its 'partner' organism (Mutualism; e.g. zooxanthellae in reef-building corals).
Target species pathogen	A pathogen typically selected from the native range of a pest species that has been targeted by a biological control or eradication programme.
Targeted port survey	A port survey with sampling regime that is aimed at detecting the presence of one or more specific pest species (see Baseline port survey).
Taxon/Taxa	Any taxonomic group/s (class, family, genus, species, sub-species, etc).
Topsides	All parts of a vessel's hull above the water line.
Transfer/Transplant	A deliberate *Translocation.*
Transgenic	Cells or tissue of an organism with genetic material containing DNA that has been artificially introduced into the germ line (see *GMO*).
Translocate/Translocation	Any deliberate or unintentional transfer of an organism or its propagules between disjunct sites. The ICES 1994 *Code of Practice on the Introductions and Transfers of Species* restricts 'Transfer' and 'Transplant' to a species translocation "*within its present range*" (i.e. both native and introduced ranges). This distinction is not followed in this review.
Triploid	Somatic cells containing three sets of chromosomes.
Unintentional introduction	An accidental, unwitting and often unknowing introduction, directly or indirectly caused by a human activity.
Vector	The physical means, agent or mechanism which facilitates the transfer of organisms or their *propagules* from one place to another (see *Pathway*).
Vessel	Includes all types of ship, barge, mobile drilling unit, work boat, fishing vessel, yacht, launch, recreational boat, submersible and other craft.

2.4 RISK BASED MANAGEMENT

It is universally accepted that preventing incursions by taking controlling actions before or at a country's border is the most cost-effective response to the problem of aquatic and terrestrial bioinvasions (e.g. Bax 2000, Wittenberg & Cock 2001). Prevention protocols use risk-based strategies to assess and prioritise all pathways which can bring unwanted marine species to a nation's shores and waterways, plus a management system to provide sufficient resources for detecting and responding to border incursions. Risk-based approaches have been adopted since no nation can afford the systems, personnel and transport/trade disruptions for inspecting or treating individual shipments on every vector and route.

2.4.1 Risk Assessment

Risk is the likelihood (probability) of a harmful event occurring, multiplied by the magnitude of the consequences if the event occurs (= level of public harm, ecosystem damage, economic loss, etc). An event which has a low probability of occurring can still pose a large risk if its harmful consequences are deemed severe or catastrophic. A conventional risk analysis involves four steps: (1) hazard identification, which requires a good understanding of the transport systems and vector/s in question; (2) hazard analysis, which takes time and money to perform reliably; (3) an exposure/consequences assessment (i.e. what becomes exposed to what should the identified event/s occur); and (4) the risk calculation and evaluation process, whose reliability and usefulness depends on the quality and completeness of the preceding steps. A fully quantified risk assessment (QRA) also includes measures of the uncertainty of its results.

Risk can be estimated by qualitative, semi-quantitative or quantitative methods, depending on the type and amount of available information and completeness of the model of the hazard under investigation (e.g. US-ANS-RAMC 1996, Hayes 1997, US-NSTC-CENR 1999, Hewitt & Hayes 2002, Raaymakers & Hilliard 2002, Russell *et al* 2003, URS-Meridian 2004). Any quarantine, coastguard or fishery agency which uses a risk-based approach for managing marine introductions therefore faces three options for its risk analysis:

(1) Performing qualitative risk assessments, such as Delphi or similar techniques to crunch group-reviewed opinions, guesstimates, score-cards etc. However the outcomes of these relatively inexpensive but essentially subjective exercises can vary according to the backgrounds and influence of the individuals or organisations involved, and the results tend to overestimate low probability/high consequence events while underestimating higher probability/lower consequence events (e.g. Haugom *et al*, in Leppäkoski et al. 2002; also Section 2.4.2); or

(2) Spending more money on semi-quantitative methods that focus on particular vectors amenable to route assessment (e.g. ballast water, hull fouling, fishing equipment) and use indirect measures of bioinvasion potential. Semi-quantitative methods are aimed at maximising the use of available data to reduce subjective input as much as possible, thereby allowing the information to 'speak for itself' (e.g. Hayes 1997, Ruiz & Carlton 2001, Raaymakers & Hilliard 2002, Clarke *et al* 2003); or

(3) Collecting detailed information on specific taxa with known harmful characteristics to permit (a) quantitative risk assessments of a single key vector such as ballast water, then (b) incorporation of its results into a real-time 'decision support system' (DSS), which is used to identify and manage the risk posed by each intended ballast tank discharge (e.g. Hayes 1998, 1999, Hayes & Hewitt 1998, Colgan 1999, Hewitt & Hayes 2002).

Option (3) is expensive and not easy to achieve owing to the number of key knowledge gaps in marine taxonomy, the precise distributions of the taxa of most interest, and the bioinvasion process. By causing rapidly increasing uncertainties with each step of a modelled invasion, these gaps preclude use of conventional QRA methods (e.g. Hayes 1997, Hewitt & Hayes 2002). A major stumbling block faced by conventional QRA has been the inability to identify which combination of species life-cycle characteristics and receiving ecosystem features provide sufficiently reliable predictors of NIS establishment and harmful invasion.

For example, an ideal 'end-point' of a ballast water risk assessment (= the level of damaging consequences should a harmful NIS establish and spread) would involve calculating, for each species potentially present in each ballast tank, some measure of its ability to establish in the receiving environment, spread and then reduce native biodiversity, disrupt a key ecosystem process and/or damage pre-identified socio-economic values. Such end-points would allow decision-takers to use risk-acceptance criteria to evaluate the cost-benefits of different management options for each pathway and associated group of species. However the more that information gaps and poorly understood steps in the invasion process force inclusion of conservative assumptions into the risk calculation, the more the risk assessment results become uncertain, uniform and of little value to cost-benefit evaluations.

On the other hand, if the consequences (end-point) of ballast water discharges are simplified and critical data gaps can be filled via research and documented evidence, the risk posed by particular vectors and routes may be estimated with more useful precision. An amenable end-point would be: "*Inoculation of any life-cycle stage of a suspected harmful species into a receiving environment, which on current evidence appears capable of permitting its survival and the likely establishment of a harmful invasive population*". Such compromise end-points are required because marine invasion science is an emerging discipline where the name of the game remains 'ecological roulette' and where the problem of determining the potential harmfulness of particular species needs to be avoided (Carlton & Geller 1993, Carlton 2002, Hewitt & Hayes 2002; Section 2.4.2).

As noted by Hewitt & Hayes (2002), expressions of risk relating to the potential for unwanted establishments carry *"…an implicit assumption that the establishment of any exotic species in the locality is an undesired event. This is equivalent to an expression of environmental value that wishes to preserve 'natural' or existing species assemblages"*. Such end-points are precautionary as they treat all known and suspected invasive species as potentially harmful and equally unwanted (i.e. 'risk species', 'next pests'; Section 2.2),. They are most suitable when there is no need to predict, compare or evaluate the ultimate consequences from incursions of particular species.

2.4.2 ASSESSING INVASIVENESS AND POTENTIAL FOR HARM

Invasion biologists have frequently resorted to listing species' traits and characteristics in attempts to predict which are likely to spread and cause harm if introduced. These include:

- reproductive mechanism/s and fecundity,
- duration and toughness of the dispersal stages,
- tolerance to local ranges in temperature, salinity and other physical factors,
- life form and habitat requirements, and
- diet or nutrient needs, growth rate and other pre-adaptive factors.

However the characteristics exhibited by a species in its native range can differ to those displayed by its populations in invaded areas (owing to genetic founder and acclimation effects). In addition, key life cycle and environmental tolerance data are often lacking, predictions versus outcomes have not been reliable, and assessments which rely heavily on expert subjective opinion can generate a false sense of security (e.g. Simberloff & Alexander 1998, Simberloff 1999, Ruiz & Carlton 2001, Hewitt & Hayes 2002).

The one factor which has shown good correlation with predicted outcomes is whether or not the species in question has been invasive elsewhere. Matches of water temperature/salinity ranges are also useful, but by themselves are not as reliable as the former predictor owing to the wide thermal/salinity tolerances of many estuarine and brackish water taxa. On the other hand, while some terrestrial invaders have expanded into novel habitats once outside their native range, the ability for marine species to occupy divergent habitats is constrained by the powerful hydrodynamic, sedimentary and physico-chemical processes that operate uniformly across the aquatic realm[5].

Environmental matching methods trialled for predicting marine bioinvasion potential have ranged from simple overlaps of climate region (one variable) and temperature/salinity range plots (four variables), to comprehensive multivariate similarity analyses using a range of environmental descriptors (e.g. Hilliard *et al* 1997b, Ruiz *et al* 2000, Gollasch 2002, Hayes *et al* 2002, Hayes & Hewitt 2002, Hewitt 2002, Ruiz & Hewitt 2002, Raaymakers & Hilliard 2002, Clarke *et al* 2003, URS-Meridian 2004).

Adopting a multivariate approach allows a wider range of coastal and inland habitat types and aquatic regimes to be resolved. For example, simple overlaps of average or extreme salinity ranges will not separate highly seasonal estuaries (those which experience a sudden, major salinity decline but only during a short monsoon or spring-melt season) from those with regular short-term salinity fluctuations caused by more uniform freshwater inputs throughout the year, as found in humid equatorial and temperate maritime regions[6].

There is also increasing support for the paradigm of aquatic ‘invader friendly’ receiving environments, since the highest numbers of marine introductions are typically associated with estuaries, harbours or bays dominated by artificial, disturbed and/or eutrophic habitats. Reduced native biodiversity and increased vacant niche space due to eutrophication, over-fishing (which also increases nutrient availability via reduced grazing pressure and standing biomass), land reclamation/urbanisation, river damming, etc, have been linked to the invasion ‘hot-spots’ and ‘meltdowns’ reported from a range of areas such as the north-west Black Sea, San Francisco Bay, Port Phillip Bay (Melbourne) and Mediterranean localities, including the Berre, Thau (Hérault) and Venice lagoons (e.g. Nichols *et al*. 1990, Cohen & Carlton 1995, Verlaque 2001, CIESM 2002, CSIRO 2002; B. Alexandrov & G. Parry, pers. comms).

Two other features of the receiving environment have been associated with an increased propensity for both aquatic and terrestrial introductions:

- Its degree of biogeographic isolation and associated percentage of endemic species. Aquatic environments with low biogeographic connectivity and high endemicity include those in the Ponto-Caspian, Eastern Mediterranean, Laurentian Great Lakes, Mississippi-Missouri Basin, southern Australia, New Zealand, Hawaii and parts of the American Pacific coast (e.g. Cox & Moore 1980, Longhurst & Pauly 1987, Veron 1995, Hilliard *et*

[5] As noted by Veron(1995), “*Biogeographic concepts developed from terrestrial biota often have very doubtful relevance to the ocean*”.

[6] The recent ballast water risk assessments undertaken for six ports by the GEF/IMO/UNDP Global Ballast Water Programme incorporated a multivariate port matching method that used 34 variables to resolve physically divergent marine, brackish and freshwater habitats. Highly seasonally estuarine ports were resolved by including measures of seasonal rainfall intensity, distance to nearest river mouth and size of catchment (Clarke *et al* 2003, URS-Meridian 2004).

al 1997, Leppäkoski & Olenin 2000). Biogeographically isolated regions which also have relatively low native marine biodiversity, such as the Hawaiian Islands, Eastern Mediterranean and Baltic Sea, have also been considered to provide vacant niche space which facilitate successful aquatic introductions (e.g. Por 1978, Baltz 1991, Hilliard *et al* 1997, Galil 2000, Leppäkoski & Olenin 2000, Hutchings *et al* 2002).

- Its latitude. The rise in NIS numbers per steps of increasing latitude has been noted along both sides of the Australia and discussed by Hilliard *et al* (1997), Hewitt (2002) and Coles & Eldredge (2002). Several reasons have been put forward as to why temperate regions may be more prone to marine bioinvasions than tropical and polar coasts (e.g. Hilliard *et al* 1997, Hewitt 2002, Hutchings *et al* 2002, Ruiz & Hewitt 2002, Barnes & Fraser 2003).

In summary, current best predictors for identifying which and where marine introductions are mostly likely to establish, spread and cause harm may be ranked as follows:

(1) Documented evidence that the species of interest has invaded several region/s and caused demonstrable harm.

(2) Limited evidence and inductive evaluations for suspecting the species of interest is potentially invasive and capable of causing harm.

(3) The degree of similarity between the climate, hydrological characteristics and aquatic habitats of the receiving region and those colonised by the species of interest in its natural and other introduced ranges.

(4) The degree of ‘invader friendliness’ of the waters where the inoculations occur. For example:

- the number of recently established NIS;
- the percentage of artificial, heavily modified or disturbed habitats that offer vacant niches due to absence or immaturity of native assemblages;
- the presence of depauperate native communities owing to eutrophication, pollution, overfishing, river dams or other disruptive processes.

(5) The range of secondary pathways available (i.e. number and frequency of local vectors and their routes that can assist regional spread).

(6) The presence of biogeographically isolated aquatic communities containing a high percentage of endemic taxa and/or offering naturally vacant niche space owing to relatively low biodiversity.

(7) The location of the receiving waters with respect to tropical/polar latitudes (20-60^{o})

However there are insufficient field data to adequately quantify these trends. There are also mechanisms that influence invasiveness on a more ‘case by case’ basis which are difficult to predict. For example, the absence of one or more pathogens, parasites or predators which controls populations in the native range by reducing fitness, fertility and/or longevity. For these reasons there remains no substitute for careful biological research on any species of concern, both in its natural and invaded habitats.

2.5 STEPS IN PATHWAY ASSESSMENT AND MANAGEMENT

Managing pathways rather than individual species is considered more precautionary and effective than targeting specific species, provided sufficient border control efforts can be mounted without removing the resources required for incursion surveillance and response (Section 5). Compared to strategies that target individual taxa, assessing pathways to identify the high risk vectors and routes is less costly and more amenable for managing marine bioinvasions. It also avoids the problem of 'false negatives', i.e. species incorrectly assessed as non-inavsive or innocuous (Section 2.2).

The first step is to identify and assess all available vectors and routes to the borders and regions of interest. Each primary and secondary pathway can then be ranked in terms of its capacity to transfer marine taxa, its geographic origin and its relative size/frequency compared to other pathways. Each pathway can be ranked according to the number of known or suspected harmful invasive species at its source plus the degree of environmental similarity between the source and terminus of the pathway (Section 2.4.2).

Addressing the risks identified by risk assessment is a critical component of risk management. It begins by comparing the results of the risk assessment against the available management options. For each identified pathway of concern, the practicality and cost of mounting control and surveillance mechanisms can be evaluated against their ability to minimise border incursions, maximise border interceptions and detect species which evade interception.

Developing a cost-effective risk-based management strategy requires logical decision-making. The mix of selected options will be different for locations or regions where species of concern are already present (i.e. existence of post-border populations). In these cases, the focus may be placed on the control of secondary pathways (containment) plus application of eradication, exclusion, control or mitigation methods to the existing population/s. For species of concern which are not yet present, the focus will be on pre-border and border actions for reducing the incidence of translocations and inoculations and maximising interceptions.

Post-border surveillance is a high value option for most marine taxa, since it increases the chance of detecting border incursions before the founder population attains a size or spatial coverage that prevents practical eradication, containment or other control options. Because of the difficulties in eradicating or containing established aquatic species, post-border surveillance surveys might appear less effective than placing all available resources on a pre-border/border prevention strategy (e.g. Wittenberg & Cock 2001, page 104). However there are no perfect and few near-prefect prevention strategies, and the ability to deal with incursions by feasible, environmentally non-damaging methods relies on the ability to detected them early enough by surveillance monitoring.

Protocols for early detections not only requires adequate surveillance but also a contingency plan that lists the pre-determined actions to be taken when a new introduction is discovered. Response plans implemented for known or suspected high-risk species need to be executed as quickly as possible, and therefore should contain sufficiently detailed and pre-agreed action schedules, funding arrangements and decision-taking mechanisms. Surveillance is a critical component of both detection and control strategies, and it has two components:

- 'Active' surveillance: this includes targeted surveys and more continuous monitoring methods (e.g. settlement devices which are regularly inspected to detect establishing population of unwanted fouling species as early as possible; see Section 4.8.4.2); and

- 'Passive' surveillance: this involves improving the awareness and invader recognition abilities of local stakeholders, communities and government personnel through mass-media, pamphlet, sign board and education campaigns.

Active Surveillance

Active surveillance includes baseline NIS surveys and follow-up monitoring. Baseline surveys typically use a wide range of sampling methods for detecting all types of NIS, while follow-up monitoring may draw upon previous results to focus on a sub-set of high risk substrates and/or use of settlement devices (e.g. Hewitt & Martin 1998, 2001, Hoedt *et al* 2001; Section 5). NIS detection objectives and sampling methods can also be added during the planning stage of surveys or research projects required for other purposes, particularly if these involve repeated sampling of aquatic biota or habitats in or near ports, industrial or urban areas, mariculture operations, fish nurseries or conservation areas (e.g. US-NRC 1993).

Methods for detecting marine NIS vary according to the differing habitat preferences of each functional group of taxa, with their detection power and amount of sampling effort heavily influenced by the conspicuousness and density of individual species within each group . Most burrowing and cryptic marine species are highly unlikely to be detected by simple visual surveys and require intensive sampling regimes, particularly if present in low numbers and small patches. Development of gene probe sensors promises more effective and cheaper methods than routine replicate sampling and sorting (Section 5).

Sampling regimes for detecting marine NIS are best focussed on locations and habitats closest to high risk entry and inoculation points, such as berth pocket, wharf face, jetty and anchorage substrates, fishing boat harbours, marinas, slipways and repair yards, navigation aids, mooring buoys, wrecks, boat ramps, mariculture facilities, power station intakes and outlets, etc. Effective execution of NIS surveys requires a project team provided with:

- personnel trained in the field-identification of known or feared introductions,
- adequate equipment for sampling each habitat and groups of taxa, and
- access to a network of marine curators and taxonomists for identifying the sorted and preserved specimens.

Passive Surveillance

Enhancing community support and vigilance requires a passive surveillance program which encourages government agencies, port personnel, slipway operators, mariculture operators, commercial fishers, fishing and diving clubs, naturalist groups and other stakeholders to be aware of the chance of encountering unwanted non-native species when visiting or working in particular areas. However unlike 'community surveys' organised to locate terrestrial weeds etc, the capacity for non-professionals to detect many marine NIS is very limited. Such surveillance is best suited for detecting relatively conspicuous and easy-to-identify seaweeds and animals in particular work locations, such as slipways and repair yards. Firms contracted to maintain port infrastructure, navigation aids, mariculture gear etc may also be encouraged to watch for conspicuous fouling species. Thus the chances of detecting marine invaders via passive surveillance will remain low unless:

- Professional biologists and experienced marine naturalists can participate in local surveys;
- Operators of slipyards, marinas, port maintenance activities, commercial fishing vessels and charter boats have been supplied identification sheets for targeted high risk species;
- Commercial and recreational fishers, SCUBA divers, surfing clubs and other 'stakeholder' community groups are provided similar material and encouraged to report any unusual species they suspect may be introduced.

3. REVIEW OF VECTORS

The principle vectors which have aided the introduction and spread of marine NIS have been hull fouling, dry ballast, canals, ballast water, fishing gear and mariculture equipment, plus shipments of edible and ornamental species, frozen foodstuffs and bait for aquaculture, aquariums, fishery and sport fishing purposes. With the exception of canals and other types of inland waterway, all of these vectors have multiple routes. Some of them intimately share routes, such as ballast water with hull fouling and hull fouling with fishing gear. In the case of canals and canalised river systems, these follow single or branching routes which provide dispersal pathways in their own right, form part of the routes taken by many vessel-based vectors, and contribute to more complex 'stepping stone' pathways involving multiple vectors.

The vast majority of marine species invasions have occurred as a result of unintentional introductions via exploration, sealing/whaling and other fishery enterprises, trading and transport ships, naval vessels, barges, drilling rig and dredging plant transfers, plus aquaculture, mariculture and tourism (Section 3.2). However there are many examples of intentional marine species introductions into the wild and this vector is described first.

3.1 INTENTIONAL INTRODUCTIONS

Virtually all intentional releases of marine NIS have been associated with the following activities:

- deliberate historic transfer and release of various macroalgae, molluscs, crustaceans and fishes for open water wild stocking for recreational, commercial and sentimental purposes.
- escape and unsanctioned / illicit release of various macroalgae, molluscs, crustaceans and fish originally imported for domestic aquarium stocking,
- import of a wide range of species shipped to public aquariums, zoos and research laboratories, some leading to unintentional escapes or deliberate releases.

Most sanctioned intentional releases comprise the many historical attempts to establish wild stocks of various prized shellfish and finfish species, typically in countries far from Europe or North America for commercial and/or recreational purposes. However one of the earliest known deliberate introductions involves the Pacific oyster *Crassostrea gigas* brought to south-west Europe. Various batches were brought from Japan by Portuguese traders during the 16th Century and released into Portuguese waters, where they established and eventually became named as *Ostrea angulata* until genetic studies in 1998 confirmed their true origin (e.g. Carlton 1999). Tens of millions of *C. gigas* spat were subsequently imported during the 20th Century into North America, Europe and Australia to establish various closed and open water mariculture operations. Other deliberate introductions of molluscs which met with varying success included shipments of European oysters (*Ostrea edulis*) and blue mussels (*Mytilus edulis* and *M. galloprovincalis*) to South America, Australia, South Africa and New Zealand (Section 4.8.4).

Examples of deliberate seaweed transfers include the 'wakame' kelp (*Undaria pinnatifida*) from Japan and *Kappaphycus* spp. from the Philippines. *Kappaphycus* was intentionally introduced to Hawaii (along with four other red algae species) and has since become a nuisance species in eutrophic bays, particularly Kaneohe Bay and Waikiki (Coles & Eldredge 2002, Eldredge & Carlton 2002, Hutchings *et al* 2002). *Undaria pinnatifida* was deliberately brought to the French north-west Atlantic coast for farming in 1983, following its accidental establishment in the Mediterranean via oyster shipments in 1971 (Section 4.8.1). This mariculture venture ultimately failed but the weed was not removed and began spreading. It was found on the United Kingdom's south coast in 2000, and has since arrived on the shores of other North European countries via this stepping-stone and/or other pathways.

Both the sporophytes (the visible seaweed) and the microscopic filamentous gametophytes of *Undaria* readily attach to hulls, while its zoospores may delay development in the darkness of ballast water tanks to survive for at least several days. Apart from its culture-mediated introductions and spread in west European coastal waters, this invasive seaweed has also been unintentionally introduced via hull fouling and/or ballast water to the coastal waters of Argentina, Australia, New Zealand and North America, where it was first discovered in California in the spring of 2000. By 2001 its fertile sporophytes were present in many Californian locations from San Francisco to Monterey Bay harbour (i.e. over a 500 km range and depths from the waterline to 25 m). The mature sporophylls (the reproductive part of the sporophyte) release 100,000 - 1,000,000 zoospores per gram of sporophyll tissue per hour during the peak 20-40 days of zoospore release, which develop into gametophytes between several hours and three days later (e.g. Saito 1975, AM 2000, Silva *et al* 2002). The remarkable reproductive and dispersal features of this species explain why almost all eradication and control attempts have been unsuccessful (Section 3.4.5.2).

Many deliberate introductions of commercial and recreational European marine species were attempted in Australia, New Zealand, North America and South America following their European colonisation, and also in the Hawaiian Islands in the 1950s-1960s (e.g. Randall 1987, Eldredge & Carlton 2002). Reasons for these attempts, which involved a wide range of biota including seaweeds, crustaceans, molluscs, diadromous salmonids and true marine fishes, typically involved sentimental and/or purely commercial aspirations to 'enrich' the stocks provided by native species. Shipments of seed stock for rearing and release were organised by government agencies, so-called 'Acclimatisation' societies and wealthy individuals.

The isolated Hawaiian Islands have a relatively depauperate tropical marine biodiversity compared to the central Indo-Pacific region, and they are virtually unique as to the number of attempted deliberate aquatic species introductions into a single area (e.g. Randall 1987, Pollard & Hutchings 1990a, Baltz 1991). These occurred until the 1960s and included both marine and estuarine fishes in attempts to boost the economic value of local fisheries as well as for sports fishing and other benefits. Of the 21 species deliberately introduced for tuna bait, commercial, sport fishing or mosquito control purposes, seven established breeding populations. However none of the latter "*fully attained what was expected of them, and all have been criticised for one negative attribute or another*" (Randall 1987). Six inadvertent fish introductions also occurred, of which three also managed to establish populations (a mugilid, mullid and lutjanid).

Attempts to establish wild stocks of non-native marine fishes have had poor to mixed success in other countries. A range of north-west Europe fishes were released into inshore, estuary and river waters of southern Australia and New Zealand during the early 20th Century, all without success. These included salmonids, flounder and other flatfishes (Pollard & Hutchings 1990b, Hine 1995). Releases of the diadromous Atlantic salmon (*Salmo salar*) into various coastal watersheds in southern Australia and New Zealand were relatively successful (as reared from eggs brought from the United Kingdom between 1868 and the 1930s), as was the case for Atlantic salmonids introduced to the west coast of Canada. However all three salmonids introduced to southern Australia and New Zealand (i.e. Atlantic salmon, brown trout [*Salmo trutta*] and Californian trout [*Salmo gairdneri*]) required government-funded hatcheries to maintain fishable stocks in each watershed. Juvenile Quinnat and Sockeye salmon (*Oncorhynchus tshawytshca* and *O. nerka*) were released by rearing from eggs brought from California and Canada. Only the Quinnat salmon managed to establish in New Zealand and this stock now forms the basis of an ocean ranching mariculture industry (Hine 1995). Other New Zealand attempts included the Atlantic blue lobster (*Homarus vulgaris*), the edible European crab (*Cancer pagarus*) and Australian penaeid prawns, as well as North Sea herring (*Clupea harengus*) and turbot (*Rhombus maximus*).

Some States in Australia and western Canada have started reviewing the benefits and risks of continued brown and rainbow trout stocking, in recognition of the impact of salmonids on native river and lake fishes. Recently the Australian Conservation Foundation supported calls by Native Fish Australia (NFA; http://www.nativefish.asn.au/) for the State Government of New South Wales (NSW) to reduce its lake and river salmonid stocking, citing evidence of negative impacts to local fish and frog species and inland water ecosystems as a whole (NSW Fisheries released 4.4 million juvenile trout into the state's rivers and lakes in 2003, mainly for recreational fly fishing; Appendix E). The NFA has argued that such stocking is in breach of both the NSW *Fisheries Management Act* 1994 and *Threatened Species Conservation Act* 1995, and that non-native salmonids should not be released into systems unless it has been scientifically determined that these pose no significant threat to native fauna. Stocking is now being reviewed and a draft strategy for fish stocking proposes increased protection for sensitive aquatic ecosystems containing endangered fish and frog species (Appendix E).

In summary, deliberate historical attempts at wild stock introductions of most marine fishes and decapod crustaceans achieved little or no success, particularly when compared to seaweeds and molluscs (oysters, mussels and clams), as well as many euryhaline or obligate freshwater fishes and some freshwater crayfishes that have been deliberately introduced into inland watersheds.

3.2 VECTORS AND PATHWAYS OF UNINTENTIONAL INTRODUCTIONS

The following sub-sections provide examples of the vectors and pathways that have led to inadvertent and often deleterious introductions, some of which provide the case histories described in Section 4.

3.2.1 Canals, Seaways and Internal Waterways

Canals and other navigable waterways which link otherwise unconnected marine waters via channelised river systems and lakes provide significant pathways for range expansions – not only for distant marine NIS but also for regional natives which had not reached previously isolated watersheds. The opening of new canals and seaways has led to various waves of marine introductions as a result of shortened international shipping routes and inception of regional barge traffic, as well as their facilitation of self-mediated range extensions.

Among the most famous canal-induced introductions are the so-called ‘Lessepsian migrations’ into the Eastern Mediterranean[7] via the Suez Canal (Box 1 and Appendix D), and the Great Lakes invasion by the sea lamprey (*Petromyzon marinus*) following the opening of the Welland Canal. The opening of the Suez Canal in 1869 and its Panama counterpart in 1914 connected the Red Sea with the Mediterranean and the West Atlantic/Caribbean with the East Pacific respectively. By significantly reducing inter-ocean travelling times, these links have significantly contributed to the increased rate of marine introductions of the 20th Century. Unlike the Panama Canal which has locks and passes through permanent fresh to brackish water lakes, the Suez has no locks. A number of Red Sea crustaceans and fishes were

7 Named after the French engineer who designed and managed construction of the Suez Canal.

found to have transited the canal after 30 years of its opening (Box 1). The canal has currently caused a remarkable influx of some 300 tropical Indo-Pacific species into the oligotrophic

BOX 1: HISTORY OF MARINE INTRODUCTIONS VIA THE SUEZ CANAL

The role of the Suez Canal as a pathway for the self-mediated migration and dispersal of marine biota took many years to develop because its original suite of water characteristics and benthic habitats were relatively inhospitable. The physicochemical characteristics remained restrictive for the first 30 years, with turbidity, salinity and temperatures generally higher than those of both adjoining seas. For a long time the hypersalinity of its southern Bitter Lakes, plus the seasonal and often substantial dilutions from influxes of River Nile waters from the north, acted as two opposing salinity barriers. However these were gradually eroded - particularly after the reduced Nile influxes following completion of the Aswan High Dam (White 1988). The variations have now almost completely disappeared, leaving salinity levels almost normal throughout the canal. During the canal's life its residual current pattern, which flows towards the Mediterranean for ten months, reversing only in August-September, has remained unchanged and favours the northward migration of Red Sea organisms. Over 200 Indo-Pacific species of macroalgae, zooplankton, crustaceans, bivalves, ascidians and fish species, plus individual marine mammals such as the sea cow (*Dugong dugon*) seen off Israel beaches in 1967, have transited the canal, with most of these establishing themselves in the East Mediterranean. Immigration rates appear to have accelerated from the 1970s onward, with new records increasing in number and their area of extension also increasing (Halim *et al* 1991).

Establishment of the Indo-Pacific immigrants has markedly increased East Mediterranean biodiversity, including several commercially valuable species (Halim 1990). Various Indo-Pacific macro-crustaceans were among the earliest colonizers. According to Gruvel (1936) the edible blue crab (*Portunus pelagicus)* appeared in Palestinian and Syrian markets in 1897. It soon became the most common commercial crab all round the East Mediterranean, while 15 brachyuran crab immigrants subsequently colonised the Levantine basin (Almaça 1985). Five Indo-Pacific and Red Sea shrimp species were recorded from this basin around 1924, i.e. *Metapenaeus stebbingi* (a Red Sea endemic), *M. monoceros*, *Penaeus japonicus*, *P. semisulcatus* and *Trachypenaeus curvirostris* (Balss 1927). These species together with the native *P. kerathurus* contribute several thousand tons to the annual commercial catch from Egyptian waters, which is dominated by *P. semisulcatus* and *P. japonicus*. In the spring of 1971 several specimens of the Indo-Pacific shrimp, *Solenocera indica* Nataraj, a new immigrant, were caught from Abu-Qir Bay (Abdel-Razek *et al* 1981).

Many Indo-Pacific fish species have been listed as reaching the Mediterranean via the Suez Canal, some possibly arriving much earlier via the pre-historic connections between the two seas. At least 13 immigrants have became commercially important in Egyptian waters and the southeast Levantine Sea. These included *Dussumieria acuta*, *Stephanolepis diaspros*, *Saurida undosquamis*, *Atule djeddaba*, *Hemiramphus far*, *Upeneus asymmetricus*, *Apogonichthyoides nigripinnis*, *U. moluccensis*, *Leiognathus klunzingeri*, *Sphyraena chrysotaenia*, *Siganus rivulatus* and *Scomberomorus commerson*. According to Ben-Tuvia (1985) the contribution of the immigrant fish species to Israel's commercial fishery in 1980–1982 was estimated to be around 16% of its total Mediterranean catch, and they were most abundant among the demersal fishes taken from sandy and muddy seafloor areas.

There has been little evidence of any major change in abundance of Mediterranean commercial species or other displacements that may be attributed to the newcomers, although ecological information on diet and niche preferences has remained meagre. Establishment of two Indo-Pacific goatfishes *Upeneus moluccensis* and *U. asymmetricus* do not appear to have influenced the abundance of corresponding Mediterranean species (*Mullus barbatus* and *M. Surmuletus*; Ben-Tuvia 1985). The migration of Red Sea biota into the East Mediterranean has been reviewed by a number of workers including Por (1978), Almaça (1985), Baltz (1991), Galil (2000). Causes for the marked ability of Indo-Pacific biota to transit the canal and establish in the East Mediterranean versus the paucity of southward movements by the Mediterranean taxa have been discussed by Almaça (1985), Ben-Tuvia (1985) and Baltz (1991). These included the net northward flow and previous salinity fluctuations of the canal, plus a 'high pressure -> low pressure' gradient considered to favour the highly diversified Indo-Pacific fauna over the impoverished East Mediterranean taxa.

[drawn mainly from Halim *et al* (1995): www.fao.org/DOCREP/003/V4890E/V4890E02.htm].

waters of the Eastern Mediterranean (Box 1; Appendix D). The overwhelming northward trend of the mass migration has been associated with the canal's predominant northerly current, the ability of the Red Sea taxa to tolerate winter conditions in the Levantine basin and the relatively depauperate nature of the Eastern Mediterranean biota (Box 1, CIESM 2002). Not all introductions into the Mediterranean are due to the canal. For example, some 5% of the Mediterranean's current inventory of molluscs comprise non-native species introduced to its western half by ballast water, hull fouling and other vectors (CIESM 2002).

Completion of the Welland Canal between Lake Ontario and Lake Erie provided a bypass around Niagara Falls, allowing the anadromous sea lamprey [8] and other marine invaders to expand their spawning and feeding areas into many parts of the upper lakes and river systems. Adult sea lampreys are large (60-90 cm) and voracious blood suckers of many native fish including salmonids. They rapidly established and decimated local populations of lake trout and other species by this feeding behaviour. The Great Lakes seaway also provided the route for other brackish and marine biota, of which the most well known is now the zebra mussel, *Dreissena polymorpha* (Section 4.2). Increasing salinity of the Great Lakes from the 1940s to 1970s, in part due to decreased freshwater discharge as well climate variations, is considered to have assisted the survival of these species (e.g. Sheath 1987, cited in ICES 1999).

The concept of using electric barriers to prevent self-mediated spread of invasive species along canals and waterways has been the subject of research and testing since the 1950s, when these barriers were first used in attempts to halt the sea lamprey invasion. Trials continued until the 1960s when they were terminated after the chemical lamprey larvicide TFM was found to provide a cheaper and more effective population containment and control method. Problems with the first generation of electrical barriers included unsafe use of alternating current, salinity conductance, power failures, debris damage and overtopping during winter spates. They could also not be used on any stretch of waterway used by trading or recreational vessels. Developments in technology have led to promising 'second generation' systems which have been recently trialled at several locations in the United States to control invasive carp and other introduced freshwater fish (Section 5.2.8.1).

Other canals which have caused significant invasions include those forming the Euro-Asian waterways (e.g. the Dnepr and Volga-Dom systems), and the Parana-Tocantis-Amazonas river links in South America. Case studies are provided in Sections 4.2 and 4.11.

3.2.2 Drifting Marine Debris

Marine debris is well known to pose environmental threats due to wildlife entanglement and ingestion, as well as being an unaesthetic factor that influences tourism. The role of buoyant marine debris as a rafting vector for fouling species has been raised by several reviewers of the marine rubbish problem, but solid field evidence remains in the infant stage. Floating plastic, packing cases and other artificial debris can form surrogate substrates for natural debris (seaweed rafts, mats of terrestrial vegetation, logs and slow moving whales, turtles and whale sharks). Floating plastic debris may also function in a similar way to ships hulls to transport organisms. Fishing nets which drift ashore after being abandoned or lost in the Pacific Ocean have been found covered with many marine organisms, and these may represent a significant drift mechanism in the Pacific Ocean (Cranfield *et al* 1998).

[8] Maturing adults of anadromous fish such as salmon and lampreys migrate into rivers and up streams to spawn, with juveniles moving downstream to feed in lakes, estuaries or open marine waters. Catadromous fishes, such as the Atlantic and West Pacific eels (*Anguilla anguiila, A. japonica, A. australis*), migrate from rivers to deepwater spawning grounds in tropical oceanic areas. Diadromous fish move both ways more regularly.

A survey of marine debris in northern New Zealand waters revealed 28 of 60 bryozoan species that had not previously been recorded, while other studies have confirmed that plastics and other persistent materials can support various encrusting fouling organisms and associated epibiota, and can also ttract a relatively diverse mobile fauna (Jokiel 1990, Minchin 1996, Winston *et al.* 1997, Gregory 1998, Wittenberg & Cock 2001, Barnes 2002a,b, Barnes & Fraser 2003, Russell *et al* 2003).

Barnes' 10-year study of stranded shoreline litter (jetsam) confirmed that plastic is the most durable type of litter, is typically more colonized than other debris material and is the dominant component of floating rubbish in most places. It also indicated the marine debris vector can threaten remote islands around the globe such as the Galapagos, as well as the Antarctic where marine litter has quintupled the amount of available floating material. Barnes & Fraser (2003) also found that fouling marine species are capable of entering Antarctic waters by this vector, particularly if global warming continues to raise water temperatures in the Peninsula region and/or weaken the circumpolar divergence (a natural and abrupt sea surface temperature barrier; see also Section 3.5).

Reducing the prevalence of synthetic materials entering the oceans requires changes in the awareness and attitudes of coastal communities and industries, plus tighter controls of existing MARPOL regulations by Port and Flag States.

3.2.3 Aquaria Releases

The most famous escapes from aquaria have so far involved the so-called 'death weed', which are aquarium-selected, cool tolerant and unusually vigorous strains of the normally tropical green alga *Caulerpa taxifolia* (see case study in Section 4.1). Escapes can occur inadvertently or by deliberate thoughtless discard when a domestic aquarium or its contents are no longer wanted. Small fragments of this strain can readily survive to grow into new plants vegetatively. Translocations of escaped plants living in open coastal waters can occur via ballast water, hull fouling and uncleaned fishing, mariculture and SCUBA diving equipment.

The aquarium pet trade is a world wide business, with international mail parcels containing aquarium stocks increasing by over 30% in recent years. Small parcels rapidly shipped by express courier companies have provided new pathways. The sources have also increased, particularly with the growth of internet mail ordering services where many types of marine organisms have become widely available (the invasive aquarium strain of *C. taxifolia* remains available to aquarium owners and can be internet ordered, although several nations are moving to restrict this trade.

The case of *Caulerpa* highlights the selection pressures that domestic, public and research aquaria can exert for producing tough, thermally tolerant strains with enhanced growth and regenerative potential. There is a need for the aquarium pet industry to promote the responsible management of domestic aquaria, including free acceptance of any unwanted specimens returned to vendors. Governments should highlight the risks and illegality of aquaria dumping, and review or strengthen their regulations as and where necessary.

The issue of genetically modified organisms (GMO) in the aquaria fish trade has also commenced, with the recent announcement of 'red-glowing' zebra fish. This has been accepted by some America States (e.g. Florida) but rejected for purchase by agencies in others (e.g. California). The issue of future accidental release or discard of GMO fishes into the wild (including transgenic salmonids; Section 3.4.4) is beyond the scope of this review.

3.2.4 Mariculture Industry

Mariculture is the aquaculture or farming of marine species. The UN's Food and Agriculture Organization (FAO) defines aquaculture as 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…*".

As the world's wild fishery stocks continue to decline, aquaculture is one the fastest growing sectors of the global food economy, increasing by more than 10% per year and currently accountings for over 30% of all consumed finfish and shellfish. In 2000, 50% of the volume of total aquaculture production came from marine waters, 5% from brackish waters and 45% from freshwater. Asia accounted for 84% of all farmed product in this year, followed by Europe at 9% and North America at 3% (Weber 2003). The vast majority of the farmed tonnage is produced in East Asia, particularly China, Japan, Korea and Thailand.

The 1990s also brought explosive growth in the open water 'ranching' of salmon, tuna and other predatory fishes, with net pens and cages proliferating in coastal waters from Norway and Scotland to Canada, Chile, New Zealand and southern Australia. The global production of true marine fishes (i.e. not including the diadromous salmonids) grew by 350% in 1985-2000 to one million tonnes, and was spread among a large number of species led by Japanese amberjack, flathead grey mullet, gilthead seabream, and silver seabream. China led the way, reportedly producing 42% of the 2000 total, followed by Japan with 24%, Egypt with 10% and Greece with 7% (Weber 2003). Farmed production of salmonids (both salmon and trout) remains larger, and grew threefold between 1985-2000 from 770,700 to 2.3 million tonnes. Australia, Canada, Chile and Norway all dramatically increased their production, mostly marine Atlantic salmon in open water pens. The dominant diadromous species produced in 2000 were Atlantic salmon (39%), milkfish (20%), Rainbow trout (20%) and Japanese eel (10%; Weber 2003).

Most farmed marine fish, including the salmonids, are fed on pellets manufactured from wild caught forage or bait fish such as anchovies and herring, which are released directly into the pens. Mussels, oysters, clams and scallops do not require feeding (they filter-feed plankton and organic particles in the water column), and are grown on the bottom or on long suspended ropes or racks. As noted by NISC, translocations for mariculture cannot be universally labelled as either or good or bad. Each needs to be judged on the positive versus potential negative impacts of the planned movement. This includes the quality of the proposed quarantine measures (to prevent unintentional transfer of disease, parasites and other hitchhikers), the chances of escape by accidental or illegal release, and the consequences if these occur.

Inadvertent introductions via mariculture operations can occur four ways:

- Escape of pathogens, parasites, commensals or other hitchhikers imported within shipments of crustacean, mollusc or fish seed-stocks which do not receive adequate screening and quarantine procedures (case studies in Sections 4.8.1 and 4.8.2).
- Self-dispersal of spawn and larvae from unconfined facilities that culture non-native stocks of sessile filter-feeding molluscs (e.g. oysters, blue mussels; Section 4.8.4).
- Escape of non-native fish or sub-species (races) from open water cages and pens (typically salmonids; below).
- Introduction of foreign pathogens in frozen or processed fish product, imported to feed ranched tuna, salmonids or other carnivorous fishes; below).

An example of the inadvertent spread of cultured molluscs is the Pacific oyster (*Crassostrea gigas*) introduced to Australia (see Section 4.8.4 for other case histories). These were brought to Australian coastal waters during the late 1940s and early 1950s but could not be cultivated on a successful economic basis until the early 1970s. By the late 1980s the *C. gigas* populations had commenced self-mediated ‘coastal creep' away from cultured areas, a process involving gradual displacement of local oyster stocks (Pollard & Hutchings 1990b). As a consequence *C. gigas* became listed as one of Australia’s marine pest species (ABWMAC 1998; see also case studies in Section 4.8.4.3).

The development of open-water ‘ranching’ methods for fish culture has caused a high rate of salmonid escapes from the net pens. Nearly 80% of farmed salmon production on the Canadian Pacific coast is reported to be based on the non-native Atlantic salmon (*Salmo salar*). Evidence indicating that escapees are now establishing wild stocks has raised concerns regarding their affect on wild populations of the native pacific salmon (*Onchorhynchus* spp.; Weber 2003). There are several cases of salmon introductions, including pink and Chinook salmon into the Great Lakes and the Chinook salmon into New Zealand (Section 3.3). While previous deliberate but sporadic attempts to introduce Atlantic salmon into British Columbian rivers (Canada) failed, evidence emerged in 1998 that regular unintentional releases of this species from farm pens has led to an establishing wild population on Vancouver Island, with upstream spawning and juveniles occurring in three watersheds (Weber 2003). Issues regarding the use of transgenic salmon stocks are also emerging (Weber 2003).

Farmed marine fish are prone to parasites which then infect local fishes, but there is no evidence suggesting that the parasites which periodically afflict penned stocks and become transmitted to local wild populations are non-native. However fish raised in crowded conditions are also very susceptible to viral and bacterial diseases which can be transmitted to distant stocks of wild fish via escape of stocked fish. One example was the reintroduction to Norway of furunculosis via import of stock fish from Scotland in 1985. The rapid spread of this bacterial disease to both wild and farmed salmon along the coast of Norway coincided with the escape of large numbers of salmon from farms, and there were widespread severe losses (Weber 2003). Other diseases found in salmonid farms, such as infectious pancreatic necrosis (IPN) and infectious salmonid anaemia (ISA), can also be transmitted to wild fish stocks. ISA can cause high mortalities and is spread by live fish, fish parts, contaminated equipment, sea lice and people handling infected fish. First reported in Norway in 1994, ISA was later found at farms in New Brunswick and Nova Scotia (Canada) and in farmed and wild salmon in Scotland and the Faeroe Islands (Weber 2003). In 2001, ISA was documented in Cobscook Bay in Maine, leading to the destruction of all salmon in net cages and a multi-million dollar government bailout of the industry (Weber 2003).

In the case of diseases introduced in imported frozen fish used for the food pellets, a significant example was the 1995 appearance of a herpes virus, which within two years decimated native pilchard stocks along the entire southern Australian coast. Analysis of causes provided good evidence of its source in frozen bait fish imported to South Australian tuna farms from Chile and/or California (Fletcher *et al* 1997, Hyatt *et al.* 1997). The epidemiology of this RNA virus event, which saw the movement of the disease both against and across ocean currents off southern Australia, plus its restriction to a single clupeid species, discounted an alternate cause involving dinoflagellate toxins (Fletcher *et al* 1997). Other reported disease translocations via intentional introductions of stock for mariculture includes *Bonamia* in oysters and *Gaffkemia* in lobsters (in Wittenberg & Cock 2001).

Because containment of stock held in open water pens is much harder to achieve than in closed systems on land, environmental assessments of these operations must assume that significant escapes will inevitably occur. The exact source, genetic make up and quarantine measures of each proposed stocking operation need to be carefully vetted. Current research is focussed on ways to prevent pen rupture by storms and by sharks, seals, sea lions, dolphins, and harbor porpoises which are frequently attracted to the pens.

The movement of fouled aquaculture equipment such as settlement lines, grow out lines, shellfish trays and fish pens between areas is a potential vector for spreading non-native biofoulers and pathogens. Movement of salmon cages contaminated with *Undaria* is believed to have been responsible for the spread of this seaweed into New Zealand's Marlborough Sounds. In Australia, regulations have been made to prevent pest species such as the northern Pacific seastar (*Asterias amurensis*), Japanese kelp (*Undaria*) and Mediterranean fanworm (*Sabella*) being transferred with mussel ropes from Port Phillip Bay to grow-out areas in Western Port Bay. Although initially judged negligible, the impact of marine aquaculture on biodiversity in Europe is now considered locally severe as a result of associated pests and the escape of cultured species that can cause genetic change in wild populations (EEA 1999, cited in EC 2002). The following table is modified from White *et al*. (2003) and summarises which types of aquaculture are associated with introductions and other environmental issues (see also FAO 2003, Weber 2003, WWF 2003).

System	Typical Species	Issues	Level of Impact
Costal water mollusc culture, open and semi-enclosed systems	Oysters, mussels, scallops, clams, abalone	Introduction of non-native spp. (incl. the stock + pathogens, parasites, and various hitch-hikers). Movement of gear can transfer diseases and pests along secondary pathways.	Varies with the level of planning and management, particularly seed stock quarantine and gear cleaning. Filter-feeding molluscs tend to improve local water quality.
Net-pens or cages	Salmon, sea bass, sea bream, tuna, grouper, snapper	Direct release of biological and chemical wastes into environment. Escapes. Introduction of non-native species and disease agents.	Considered High.
Coastal brackish water ponds	Penaeid prawns and shrimp	Discharge of high organic waste loads, destruction of mangroves, spread of diseases	Considered High.
Flow-throughs/ Raceways	Hybrid striped bass, trouts	Some waste discharge, no data on introductions.	Moderate. Can be minimized with best management practices.
Inland ponds	F'water crayfish, yabbies, catfish, carp, tilapia, perch, hybrid striped bass.	Some waste discharge. Some use of non-native species, leading to invasions.	Moderate. Can be minimized with proper management.
Re-circulating closed systems	Tilapia, hybrid striped bass, sturgeon	Small amount of waste discharge. Energy intensive.	Generally low. Energy consumption can be reduced.

3.2.5 Commercial, Military and Recreational Vessels

3.2.5.1 Ballast and Hull Fouling Vectors

The wide range of contemporary vessel types that are used for trade, dredging, bridge construction, offshore oil and gas fields development, fishing, cruising, recreational boating and military uses, provide two main vectors: Ballast (+ bilge) water and hull fouling[9].

[9] Many cryptogenic marine species can be traced to pre-historic and historic voyages of discovery, trade and colonisation, with the immense timescales (>3,000 years) implying major involvement of both hull fouling and solid 'dry' ballast of sailing vessels. Dry ballast was typically shoreline boulders or shingle containing substantial quantities of sand, seaweed and other biota, and carried in very damp if not soaking conditions in the bottom of sailing ships. It was discharged casually at certain shoreline points in most ports and harbours, typically to be re-used by other vessels. It was probably responsible for introducing various sand-dwelling meiofauna as well as littoral macrobiota and coastal plants. It remained a significant vector until its widespread discontinuation in favour of water barrels then purpose-designed tanks, which were discharged in bulk from about 1910 (e.g. Herfort & Kerr, in Hilliard *et al*. 1997a).

Ballast Water: Ballast water was first recognised as a vector for inadvertent marine species introductions in 1908, and was occasionally reported and discussed by various workers until the 1985 publication of Carlton's seminal review of trans- and interoceanic ballast discharges. The review highlighted several factors about the rising importance of the ballast water vector, including the progressive increase in the number and speed of trans-oceanic voyages, the additional reduction in journey times owing to the Suez, Panama and other canals, and the increasing use of larger, purpose-built dry and liquid cargo bulk carriers dedicated to 'one-way' delivery voyages (requiring more frequent use of large quantities of ballast water for the return journey). Since then much management effort and public attention on ship-mediated bioinvasions have been focussed on the primary and secondary pathways provided by this vector, which includes the suspended sediment and other particulates that become uplifted into the tanks then settle to provide additional biota habitat and protection from tank flushing during ballast water exchanges.

Most major and several minor phyla have been shown to survive voyages in ballast tanks, and a wide variety of marine species has been introduced by this vector (e.g. Baldwyn 1992, Carlton 1985, 1987, 1989, 1992, Carlton & Geller 1993, Cohen & Carlton 1995, Hutchings 1992, Rigby & Hallegraeff 1994, Williams *et al* 1988, Hilliard *et al* 1997a; see Section 4 for several case studies). Bilge water is usually linked to the suspected translocation of pathogens such as *Vibrio* cholera strains but is often included with the ballast water for convenience. It may act as a vector for marine plants and animals in some types of fishing vessels, barges and cruising yachts. However the bilge spaces of most types of conventional motor vessel are often too warm or oily for marine fauna to survive, and many countries actively enforce rules constraining the discharge of bilge water into coastal or inland waters.

Removing or inactivating the wide range of biota that often become entrained during ballast water intake has remained an intractable problem, owing to the lack of 'off-the-shelf' methods enabling clean, safe and economic treatment. This is particularly the case for the smaller organisms and larval stages (<80 µm), plus the small (~20 µm) and very 'tough' resting stage cysts of the red-tide causing dinoflagellates and other microalgae. These cysts cannot be removed by conventional mechanical filtration or killed without resort to expensive and toxic chemicals or heat treatment. Heating to ~40^{o}C, ultrafiltration and UV irradiation are among the most promising methods investigated to date, although all require more R&D and scientifically robust pilot trials. It is not yet clear if deep-water (>200 m) ballast exchanges and improved 'micro-management' of ballasting practises, as promulgated by an increasing number of Port States and the IMO during the 1990s, will produce declines in marine NIS introduction rates prior to the development of effective treatments. Details on the treatment and management of ballast water can be found in the sources and links listed in Appendix A.

Hull Fouling: This vector can translocate marine NIS as readily on small vessels as on barges, mobile drilling units, floating docks and large ships (e.g.AMOG 2002, Hutchings *et al* 2002, Minchin & Gollasch 2002). Hull fouling includes all external wetted surfaces including sea chests, bilge keels, anode blocks, rudder pins, propellers, shaft protectors, echo sounder transduces and log probes. Hull fouling also includes all internal surfaces and niches, including anchor wells, chain lockers, bilge spaces, fishing gear, bait lockers, cooling water intakes, strainers and pipework. All of the above should be considered part of the hull fouling vector (eg. Rainer 1995, AMOG 2002, Hutchings *et al* 2002, C. Hewitt, pers. comm.).

During the 1980s hull fouling was widely assumed to no longer be a significant vector. Arguments commonly advanced to support this view were the retirement of most wooden hulled trading ships by the 1940s, the development of more efficient, self-ablating anti-fouling systems using TBT, the fast speeds of modern ships and their much shorter turn-around times in port - as achieved by containerisation and modern bulk handling equipment.

However it became increasingly apparent during the 1990s that hull fouling was remaining a significant vector in both primary and secondary pathways - particularly for non-trading vessels where the need for smooth hulls (fuel efficiency) is not critical, such as barges, drilling platforms and artesanal fishing craft, as well as many commercial trawlers, cruising yachts and recreational launches. Even trailered recreational boats have provided a hull fouling vector by connecting isolated lakes and waterways in North America (Section 4.2).

Several case studies in Section 4 include examples where the ability of invasive marine species to spread from their initial establishment site was enhanced by hull fouling along secondary pathways (e.g. Sections 4.1 - 4.3). Hull fouling also continues to provide a primary pathway for any ship, mobile drilling unit or other craft which, after being laid up, moored or worked at a single site for several months or years, is transferred to a distant harbour or work site where it remains for another extended period. After arriving from a distant port or work site, any vessels which are laid up for an extended period in a harbour, anchorage or estuary provide their fouling biota the opportunity to mature and spawn, with nearby wharf piles and breakwaters offering convenient settlement areas. Many non-trading vessels undergo these types of movements without a thorough hull clean (e.g. dredgers, barges, drilling platforms, decommissioned warships, trawlers and yachts) since, unlike most trading vessels, the increased drag and fuel consumption incurred from biofouling are not as critical to operational profit-margins. If heavily fouled vessels arrive in a new port with already mature species, cues within enclosed harbour basins or estuaries can stimulate these adults to spawn within a few hours of arrival (see *Military Vessels* below).

Long stationary periods constrain the self-ablating / ‘self-polishing’ action of modern anti-fouling coatings. This increases the opportunity for thick biofilms to develop, and for copper- and/or TBT-resistant taxa to colonise excessively leached or damaged coating areas (including the dry-docking support strips (DDSS) which miss the previous coating). Biofilms produced by various bacteria, diatoms and filamentous algae help them tolerate and ‘pre-condition’ TBT-based coatings, while serpulid tube worms (particularly *Hydroides* spp.) can tolerate low copper levels, including unablated copper-based anti-fouling coatings and uncoated cupro-nickel surfaces of log probes, valves, intake apertures, rudder pins, propeller studs, etc (e.g. AMOG 2002, J. Lewis, DSTO pers comm., URS author observations). Build-up and senescence of pioneering foulers, which include green filamentous algae, bryozoans, tube worms and barnacles, provides amenable substrates and micro-crevices that attract further settlements.

It has also been recognised that many yacht and recreational boat owners do not follow (or cannot afford) the advised cleaning and re-coating dates (Floerl & Inglis 2002, Hutchings *et al* 2002), while many coastal craft and artesanal fishing vessels in developing nations have no anti-fouling coatings and instead are occasionally scraped in-water or by shoreline careening (Russell *et al* 2003). While the latter craft do not generally provide a long distance vector unless transferred or used for illicit smuggling or fishing enterprises, the wide-ranging ‘stop-start’ voyages of cruising yachts and some types of artesanal fishing vessels make these craft a promiscuous vector (Pyne 1999, Hutchings *et al* 2002, Kinloch *et al* 2003, Russell *et al* 2003).

Where anti-fouling coatings are old, damaged or absent, surfaces and crevices become colonised by communities containing members from the following biofouling groups:

- biofilms developed by bacteria, cyanobacteria and diatoms;
- filamentous green algae (often *Enteromorpha* spp.) and turfing red and brown algae;
- sessile animals including sponges, hydroids, corals, sea anemones, tube-building worms, barnacles, bivalve molluscs, bryozoans and sea squirts (all of which adhere to suitable substrates and spread via broadcast spawning, with varying durations of larval life); and

- mobile benthic and epibenthic animals, including errant polychaete worms, skeleton shrimps, amphipods, isopods, crabs, nudibranchs, whelks, crinoids and territorial fishes (esp. Gobiidae and similar forms). This fauna avoids dislodgment by either:
  - clinging and grasping to other fouling species or the sheltered parts of the hull;
  - nestling in microspaces amongst established or dead encrusting species; or
  - sheltering within hull apertures and pipework (includes small fishes).

In addition, there may be a range of commensals, parasites and pathogens intimately accompanying members of the above biota. Many fouling species can adhere strongly, grow quickly and reach sexual maturity before their eventual dislodgement due to size-induced drag, hull cleaning or natural senescence. The diversity of a fouling community typically increases on surfaces which are subjected to long periods of relatively uninterrupted static immersion (e.g. drilling rigs, barges, floating docks and laid-up or decommissioned vessels), and it can include a range of foliaceous green and brown seaweeds, sponges, sea anemones, soft corals and even hard corals depending on location (e.g. Bright *et al* 1994, Rainer 1995, Hay & Dodgshun 1997, DeFelice 1999, AMOG 2002).

Heavy fouling on laid up vessels may carry an average of 5 kg of material per square metre (Walters 1996). Laid up vessels which receive dry-dock or in-water hull cleaning, propeller polishing and hull maintenance activities before being moved to a new region decrease the risk of NIS introductions, and greatly increase this risk if in-water cleaning is carried out after such voyages. Crushing of invertebrate species can release eggs and sperm, while fragments of macroalgae such as *Caulerpa* and worms such as *Sabella* can regenerate (Rainer 1995, AMOG 2002; case studies in Sections 4.1 and 4.6). Together with mobile organisms, byssal mussels and other molluscs, these taxa can also be dislodged intact via hull cleaning then swept by currents onto nearby substrates where they can settle and re-attach such as pilings, rocks, or rubble and sand patches (Walters 1996, AMOG 2002).

Preventing marine NIS introductions and spread via vessel fouling requires adherence to effective hull cleaning and anti-fouling programs, with sea chests and seawater systems examined and cleaned on a regular basis. This applies to all vessels, particularly those that have been laid up for long periods. Education programs are required to make boat operators and ship owners aware of the potential for their vessels to transport unwanted fouling NIS and the steps they should take to reduce this vector (Section 4.2). Slipways and dry docks also provide inoculation sources, especially if the dislodged material is not trapped and removed to a land fill site. Several codes have been developed for the cleaning of commercial and recreational vessel hulls in Australia, New Zealand and North America (Appendix A).

3.2.5.2 Ballast and Hull Fouling Vector Contributions by Vessel Type

The following sub-sections highlight which types of vessel provide significant ballast water and/or hull fouling vectors.

Trading Ships: These form the majority of the world's fleet. The most common classes are chemical tankers, container ships, crude oil, gas and dry bulk carriers, general cargo ships, livestock carriers, product tankers, vehicles carriers, various 'roll-on roll-off' ferries and cargo ships (ro-ro vessels). These classes have typically been more closely linked to the ballast than hull fouling vector owing to the economic imperatives of avoiding biofouled hulls (a significant reduction in fuel efficiency) and achieving fast turn-around times in port[10]. With

[10] This does not imply negligible hull fouling risk. While their general hull surface may remain relatively free of fouling, build-ups often occur in sea-chests and other crevices which offer protection from turbulent flow. Recent studies on this topic include AMOG (2002), Dodgshun & Coutts (2002), Coutts *et al* (2003), URS (2003).

the progressive and continuing development of larger, faster ships with larger and cleaner (dedicated) ballast tanks since the late 1950s, international trading vessels became a major if not largest vector of marine introductions from the 1960s onward. Typical ballast water intakes rates are between 200 and 1,000 tonnes/hour, while discharges from large oil and dry bulk carriers are in the 1,000 – 2,500 tonnes/hour range. Quantities carried when vessels have no cargo are typically 20-38% of their deadweight tonnage, depending on vessel class. It is generally held that the origin, storage time and frequency of ballast water discharges all influence the risk of successful introductions more than the particular volume carried in individual or all tanks. However the temperature, oxygen level and general water quality in large tanks tend to fluctuate and deteriorate less quickly than in small tanks owing to the surface area-volume effect. Therefore the largest and cleanest tanks (including use of cargo holds in some classes) will generally contain the largest numbers of surviving organisms when other factors are equal (e.g. Kelly 1992). Tank location also affects survivorship, with topside ‘wing’ tanks of bulk carriers most prone to marked heating or cooling during a voyage.

Construction Barges: Barges have been implicated in transfer via hull fouling and ballast water. Port terminal developments and bridge construction projects across rivers, estuaries and embayments sometimes employ barges, either to move pre-assembled sections into place for lifting, or to support a heavy lift crane and other gear. Their trim and precise elevation for lifting and assembly work is often controlled by ballast water. They are often laid up for lengthy periods in some quiet backwater of a port or estuary between projects. However their hulls are not usually given regular cleans or anti-fouling coatings as fuel efficiency is not a critical factor. A construction barge from Japan was the source of the Pacific oyster introduction to New Zealand (Section 4.8.1), while concerns have been raised on the ability of their ballast water to spread invasive species (e.g. water chestnut seeds between river systems and watersheds in New York State). Both construction and river trading barges have been implicated in the spread of *Dreissena polymorpha* and other mussels via inland waterways in Europe, North America and South America (the former provide connections to three different seas; Sections 4.2 and 4.10). Other examples of barge transfers include a ‘port hopping’ spread of the giant fan worm *S. spallanzanii* between Western Australian ports (Section 4.6).

Drilling Platforms and Drilling Barges: The underwater surfaces of drilling platforms and drilling barges offer a wide variety of underwater apertures and structures providing shelter from turbulent flow, and their slow towage speeds prevent the turbulent removal of heavy growth. Drilling units often spend extended periods in a port or port anchorage before and after tows to and from remote work sites, typically in shallow shelfal waters. Their extended stays in both port and coastal waters provide many fouling taxa increased opportunities to settle, grow to maturity and spawn. If this occurs in port waters, nearby breakwaters and wharf piles provide convenient settlement areas.

There is no doubt that the development and increased low-distance movements of semi-submersible and jack-up drilling platforms since the 1950s have provided an additional fouling vector for introductions to and from oil and gas exploration regions in the Atlantic, Gulf of Mexico/Caribbean and Indo-Pacific. Heavily fouled drilling platforms have been reported to be colonised by a wide range of species, including reef-building coral species and fish (e.g. in the Gulf of Mexico and following long distance tows to New Zealand; Bright *et al*. 1991, Cranfield *et al*. 1998). A drilling platform that arrived in New Zealand after a series of staged tows from Japan in 1975 was found to be heavily fouled by a range of biota, including green and red macroalgae, eight barnacle species representing three genera of north-west and west Pacific genera (*Tetraclita*, *Balanus* and *Megabalanus*), Japanese grapsid crabs (*Plagusia depressa tuberculata*) and sergeant-major fish (*Abudefduf saxatilis*) from the Solomon Islands (Foster & William, in AMOG 2002). Corals can colonise platforms and other mobile units if these are working in areas ‘down-current’ from distant reef tracts, as reported for the coral depauperate western region of the Gulf of Mexico (Bright *et al*. 1994).

Dredges: Large cutter suction and trailer hopper dredges are complex, self-propelled and expensive to maintain vessels, and they are typically engaged for major port developments that require significant capital (developmental) dredging. Many operate on a world wide or ocean-basin basis, moving from project to project at relatively slow speeds (~12 knots) to fulfil contracts that typically require 2-6 months of work at one site. Their design provides many spaces and semi-enclosed compartments promoting the settlement of a wide range of hull fouling organisms. Unless thorough cleaning programs are carefully applied to the hull, hopper, ladder and other dredging assemblies between projects, these vessels are capable of making trans-oceanic transfers of a range of sessile and mobile species. A recent example comprised the arrival a large cutter suction dredge directly from the Caribbean to Western Australia, a voyage requiring a single and short crew change and bunkering stop near the exit of the Suez Canal. While the hull was relatively clear of fouling organisms except for typical oceanic forms (filamentous algae and goose barnacles), inspection by marine scientists during its arrival quarantine procedures found seven Caribbean taxa which had survived the journey in a sheltered compartment at the base of the cutter arm ladder, including barnacles, crabs and Thaid whelks (URS and Western Australian Museum, unpublished data). Smaller, local dredges, including both purpose-built trailer hopper vessels and modified barges used for clam-shell dredging, can provide regional ‘port-hopping’ secondary pathways which contribute to the secondary invasions of established pest species (Section 4.6).

Military Shipping: Many incidents have been reported of military shipping causing introductions via hull fouling. Because of their special operational requirements, the design and movements of both commissioned and decommissioned fighting ships provide a range of opportunities for these vessels to act as significant hull fouling vectors. While the hulls of commissioned warships are regularly maintained in a well organised manner by the majority of navies, the number of additional water spaces on a fighting ship hull provides more niches than typical merchant ships. These include multiple sea chests (often 5-7), various emergency fire-fighting intakes, duplicated intakes and outlets for auxiliary units, and special sonar domes and underwater housings for auxiliary propulsion units. Decommissioned warships are often laid up for lengthy periods (years) before eventually being towed at slow speed to a distant location for either major refit and recommissioning, target practise in deep sea locations, scuttling in coastal waters to provide an artificial fishing or diving reef, or to a mooring near a breakers yard.

All such movements require a careful hull assessment and pre-voyage cleaning operation to avoid significant translocations of potentially well-established fouling communities. Examples recorded in Hawaii include the 1999 arrival of a very heavily fouled military floating dock which had been towed from San Diego to Barber’s Point harbour. A cleaning operation was instigated and only one local long term establishment has been recorded (a non-native brown macroalga *Dictyota flabellata* in the harbour itself; Godwin 2003).

In another case, arrival of the battleship USS *Missouri*, which was carrying a mature blue mussel community that had escaped a previous freshwater cleaning operation[11], caused the first reported example of a ‘stepping stone’ introduction pathway between vessels. In this instance, the temperature and salinity change experienced by the mussels on the ship’s entry to Pearl Harbour is thought to have acted as their stimulus to spawn, which they did within hours of arrival. A nearby submarine, which departed within a day of the *Missouri’s* arrival,

[11] Owing to their deep location on the hull, the mussels survived in the salt water wedge while the ship had been anchored in freshwater reaches of an Oregon river to kill its fouling biota prior to its departure to Hawaii.

later reported a massive settlement of blue mussels in its open water compartments and pipework (Apte *et al* 2000).

Fishing Vessels: Many trawlers and other commercial fishing vessels are operated on very tight budgets owing to the current status of many wild fishery stocks. The level of hull maintenance and anti-fouling protection can therefore be low, particularly for vessels laid up and then later sold off and moved to a distant fishery. An 80 m Georgian trawler which was transferred to New Zealand following a two year lay up in the Black Sea provides one example. This trawler arrived in Auckland with massive hull fouling in 1995 and a dry-docking operating was hurriedly arranged. Over 50 tonnes of fouling growth was removed, much of it alive (Hay 1999). Hull fouling on fishing vessels has also been invoked for the spread of *Undaria* between fishing harbours in New Zealand. Relini *et al*. (2000) have reported the role played by fishing vessels and their gear in the spread of *Caulerpa taxifolia* fragments in the Mediterranean Sea (Section 4.1).

While fishing boats are usually associated with hull fouling vector, artesanal craft working in warm water archipelago areas often have more open deck designs allowing build up of relatively clean bilge water. However the vast majority of these type of boats do not usually undergo long distance voyages, unless purchased or hired for illicit fishing or people smuggling voyages (Russell *et al* 2003). When modern or old fishing vessels are seized for an illicit activity and commandeered to a reception port, quarantine checks need to include both the external hull and internal bilge areas for the presence and treatment of non-native fouling biota and pathogens. More information on the vector risks of fishing vessels is available in Kinloch *et al* 2003 and Russell *et al* 2003).

Non-Trading Commercial and Government Agency Vessels: These comprise a wide range of generally small working and patrol vessels, and their risk as hull fouling vectors has been examined by Kinloch *et al* (2003). The largest comprise cable-layers, research ships and offshore supply vessels, with hull lengths in the 50-100 m range. The remainder are typically less than 50 m long, and include government agency patrol boats (Coastguard, Customs and Fisheries), port and harbour services craft (tugs, pilot launches and lifeboats), plus various small passenger ferries, water taxis and fishing and dive charter boats.

These vessels are usually relatively well maintained and, with the exception of the first group, typically have short-range operations from fixed bases. However for nations with large Exclusive Economic and Fishery Zones (including archipelagic and remote island states), their Coastguard, Customs and/or Fisheries patrol vessels may undertake long range operations to visit distant and isolated locations containing reefs and islands with high wild stock fishery and/or conservation values. These vessels are capable of transferring unwanted marine species if they have been infected by non-native fouling organisms when resting at home ports. Despite their smooth and polished hulls, mussel infections have been found in the water strainer and pipework of a long distance Customs launch (Russell *et al* 2003).

Recreational Vessels: This group includes offshore and inshore racing and cruising yachts and motor launches (kept in marinas or on moorings or boat racks due to their size; >6 m), and various trailered cabin-cruisers, runabouts, day-sailers and other craft which are typically in the 4-6 m length range. International/offshore racing yachts are kept clean of biofouling to maximise their speed. International Sailing Federation rulings now allow some of these classes to carry up to eight tonnes of ballast trim water, and this has interesting implications regarding the locations where they may uptake and discharge trim water.

International cruising yachts typically undertake long, slow voyages containing several legs, each interspersed with sojourns in various anchorages, marinas or harbours. Compared to racing yachts they are generally operated on a less vigorous if not highly lax basis, some on a shoestring budget where hull cleaning and maintenance is carried out *ad hoc* when a safe careening or snorkelling opportunity arises. Because weight is less important, most cruising yachts have an inboard auxiliary motor and a seawater cooling circuit. The majority of international cruising yachts follow favourable seasonal trade wind routes within the sub-tropical and tropical belts of the Pacific, Indian and Atlantic Oceans, and across basins such as the Mediterranean and parts of the Caribbean. These yachts can cover considerable distances on a single cruise and may visit many far-flung locations, including places not generally visited by trading ships or fishing vessels. They typically seek areas with significant environmental and conservation values such as remote atolls and pristine bays, in between visits to trading ports, fishing harbours or marinas for revictualling and/or temporary lay-up.

Because of their propensity to undertake long-range and essentially promiscuous voyages, cruising yachts have the potential to become infected and inoculate several locations on a single cruise (Kinloch *et al* 2003, Russell *et al* 2003; case study in Section 4.3). In response to the growing evidence for their role as a primary pathway for unwanted fouling species, a hull inspection program was started in Auckland in 2002, while yachts have been inspected by divers before entering the marinas at Darwin since 1999 (Section 4.3). Between 400-500 international cruising yachts visit New Zealand each year and some 100 of these have been inspected as part of program to develop a video ‘HullCam’ to save diver costs (NIWA 2003).

Many ‘home’ (domestic) cruising yachts are also operated on casual basis, with similar lax attention paid to anti-fouling condition. As with motor launches, cruising yachts may remain for extended periods within marinas before moving to a disjunct harbour, either for a cruising purpose or following its sale. The movements of domestic cruising yachts and motor launches can therefore present a significant secondary pathway for the spread of marine pests, and have been implicated in spreading the Japanese seaweed *Undaria pinnatifida* in both southern Tasmania and New Zealand (Section 4.8.1; Floerl & Inglis 2001, Kinloch *et al*. 2003, Russell *et al*. 2003). A case study involving the ability of trailered recreational boats to transfer pest species between waterways is in Section 4.2.

Derelicts and Shipwrecks: Derelict and abandoned vessels are often found in the backwaters and peripheries of ports, marinas, bays, lagoons and estuaries. Abandoned fully or partly submerged hulks may act as ‘reservoirs’ of fouling NIS, providing a significant source of spawn every breeding season. Most derelicts are previous privately-owned non-trading craft, and they may remain for many months or years if ownership is unknown or abdicated. Unless totally wrecked, trading vessels are rarely abandoned if only because of their value to salvage companies.

The ability of commercial vessel strandings and sinkings to infect relatively pristine offshore reserves has been reviewed by Russell *et al* (2003). NIWA (2003) has also described the response actions taken in 2000 at the remote and relatively pristine Chatham Islands (well offshore from New Zealand), when a fishing boat sank with the Japanese kelp *Undaria* attached to its hull. The NZ Ministry of Fisheries initially ordered the vessel to be moved using its powers under the *Biosecurity Act* 1993 but bad weather prevented salvage attempts.

It was then decided to use heat-treatment to eradicate the weed. This was achieved using plywood boxes with foam seals and attached to the hull by magnets. Electric elements inside the boxes (powered by a diesel generator on the surface support vessel) heated the seawater to 70ºC for 10 minutes, with a flame torch used for inaccessible areas. It took divers four weeks to complete the treatment, and a monthly monitoring programme over the past three years indicates the operation was successful. The island shorelines were also surveyed regularly for *Undaria* and no plants have been found.

Removing Japanese kelp (*Undaria pinnatifida*) by heat treatment from a fishing vessel wrecked in the Chatham Islands, New Zealand

Fishing Gear

The transfer or sale of uncleaned fishing equipment provides a fouling vector similar to vessel hull fouling, and is considered most significant as a potential secondary pathway for the translocation of pest macroalgae such as *Caulerpa taxifolia* (Section 4.1), *Codium tomentosoides, Sargassum muticum* and *Undaria pinnatifida* (Section 4.8.1) Uncleaned trawl and other bottom touching nets are also capable of transferring benthic pest fauna such as zebra mussels (*Dreissena polymorpha*; Section 4.2), Japanese starfish (*Asterias amurensis*; Section 4.5) and giant fan worms (*Sabella spallanzanii*; Section 4.6). Many agencies and fishing organisations have developed codes, guidelines and regulations on the need to clean trailer boats and fishing gear thoroughly before moving it to new locations (see Section 4.2).

3.2.6 SCUBA and Snorkelling Equipment

Diving equipment provides several places where pieces of seaweed can easily become entangled and lodged. Many algae pests have the ability to survive emersion for several days if conditions remain damp, and can regenerate from small fragments. Dive tourism often involves visits to several divergent locations within 2-4 days, and thus diving gear can act as vectors in secondary pathways that enhance the spread of algae. This has been reported the case for the spread of Japanese kelp (*Undaria pinnatifida*) on the east coast Tasmania (Kinloch *et al* 2003) and for invasive macroalgae in Hawaiian eutrophic bays (SL Coles, pers. comm.). Codes for inspecting and cleaning diving gear, particularly straps of fins, buoyancy vests, knife sheaths and regulator stages are being applied in the Hawaiian tourism industry.

3.3 NATURAL RANGE EXPANSIONS

Natural perturbations and cycles in solar intensity, planetary tilt, ocean currents and weather systems, together with human activities such as urbanisation and fossil fuel burning, combine to cause regional and global climate variations and change over decadal scales and longer. It has been speculated that regional cycles in rainfall and thermal extrema help explain why some introduced species have undergone ‘boom-bust’ cycles in local abundance, such as the Chinese mitten crab in German coastal areas during the 20th Century (Section 4. 4).

Long-period alteration to weather and/or water current patterns have also been put forward as possible reasons as to why some introduced populations remain small for many years, showing little propensity for spreading until switching into an relatively rapid expansionary phase (Wittenberg & Cock 2001). However there many other factors that may be equally if not more responsible, including acclimation and genetic change within the founder population, local reduction in pollutant levels, removal of some previously constraining physical feature or native biological control, and/or favourable ‘supply-side’ shifts in recruitment dynamics.

Sudden changes in abundance are not uncommon in native populations, including the population booms of the Northern Pacific seastar (*Asterias amurensis*) within its endemic range, and the Crown of Thorns starfish (*Acanthaster planci*) in the tropical Indo-Pacific. These major but apparently natural swings in population size have been related to fluctuations in weather patterns, water currents, nutrients and other planktonic conditions, as these may readily promote high levels of larval survivorship, settlement and recruitment success. Several workers have shown how small climate fluctuations may generate large changes in marine communities through alteration of predation rates and food-chain structure (e.g. in Bianchi & Morri 2000).

In the case of natural range expansions associated with the marked global warming trend over the past century, these have been reported for the Ligurian Sea in the Mediterranean, the English Channel and the coastal waters off North Carolina, California and Western Australia (Hutchins 1991, Wooller *et al*. 1991, [Barry *et al*. 1995, Southward *et al*. 1995, Parker & Dixon 1998, Sagarin *et al*. 1999] cited in Bianchi & Morri 2000). Conversely, there has been a retreat of native cold water forms as coastal water temperatures rise. This includes the southward displacement of the giant kelp beds (*Macrocystis pyrifera*) off south-east Australia, with net southward retreat being accelerated by infill of *Undaria pinnatifida* (Edyvane 2003).

The fossil records shows the marked tendency for major marine species radiations to involve movement and dispersal of warm-water forms to cooler water regions, rather than vice versa. As with many terrestrial biota, these radiations have occurred on many occasions, the last being the rapid Holocene re-invasion and infill of temperate and boreal regions by taxa which had been compressed into narrow temperate and subtropical belts during the last ice age (e.g. Cox & Moore, 1980). Recent (20^{th} Century) poleward expansions of subtropical and tropical marine and coastal species are well documented (including corals, molluscs, fishes, seabirds and coastal plants) and often linked to other evidence for global greenhouse gas warming (e.g. Hutchins 1991, Wooller *et al*. 1991, Bianchi & Morri 2000).

4. CASE STUDIES

This section contains a broad range of case studies which were chosen to provide examples of different vectors and routes, the ‘gradual’ versus ‘explosive’ or ‘boom-bust’ appearances of introduced species, and differences in the timing and types of management response following the initial reported discovery, as a result of differences in perceptions and priorities over time and between regions.

In line with GISP’s *Toolkit of IAS Prevention and Management Practices* (Wittenberg & Cock, 2001), each case attempts to summarise the current distribution and spatial extent of the organism, methods of discovery, and the types of responses, impacts and outcomes to date. Some have been drawn from circulated pro-forma and from web-based tables and pages (Appendix A). Many of these sources list information such as invasion chronology and locations, current known or predicted ranges, observed or predicted effects, response actions taken, agencies involved, costs, mitigation attempts, key references and contact addresses.

4.1 HISTORY AND CURRENT RESPONSES TO THE ‘DEATH WEED’ - *CAULERPA TAXIFOLIA* (Aquarium Strain)

(photo : Alan Millar, Royal Botanic Gardens, Sydney)

Caulerpa taxifolia is a green seaweed (Chlorophyte macroalgae) with a natural distribution throughout tropical and sub-tropical regions including northern Australia. It is primarily a subtidal species that has running stolons and feather-like fronds that can colonise both hard and soft substrata.

The first reported appearance of the “aquarium strain” in unconfined coastal waters was close to the Monaco Oceanographic Aquarium in the Mediterranean in 1984, where it was covering an area of only one square metre. It was also the first time *C. taxifolia* had been found in temperate waters. Its subsequent coverage in this region rose to 3 hectares (ha) by 1990, 30 ha in 1991, 427 ha in 1992, 1,300 ha in 1993 and more than 3,000 hectares by 1996.

It has since spread widely within the Mediterranean to colonise thousands of hectares of subtidal hard and soft substrata, and where it is reported to overgrow natural seagrasses and reduce fishery resources. It has become dubbed the ‘aquarium strain death weed’ because of its ability to escape (and be casually released) from public and private aquaria, where it is a popular

decoration owing to its selection for cool temperature tolerance, rapid establishment by vegetative growth, and its distaste to herbivorous fish.
Eradication in the Mediterranean is no longer considered feasible but the European Community has supported a containment action at the Port Cros Marine National Park (France). A 1998 petition signed by marine ecologists and invasive species researchers sent to the US Department of the Interior in 1998 forewarned of the threat posed by the aquarium strain if accidentally introduced to US coastal waters (Box 2).

BOX 2: 1998 PETITION ON *CAULERPA TAXIFOLIA* TO US GOVERNMENT

"An aquarium-bred clone of the green seaweed, Caulerpa taxifolia, has invaded the Mediterranean coasts of France and Italy and now covers thousands of acres of the coastal zone. As ecologists and exotic species research scientists, we recommend that steps be taken immediately to keep this invasive seaweed out of United States waters. France, Spain and Australia have already banned the possession, transport or sale of this dangerous organism. However, it continues to be available for importation and sale in the United States for use in public or private aquariums. If this practice continues, it is likely only a matter of time before the Mediterranean clone of Caulerpa taxifolia is released and becomes established in the United States, threatening coastal waters and coral reefs from North Carolina to Florida and the Gulf of Mexico, and in southern California, Hawaii, Puerto Rico, the U.S. Virgin Islands, Guam and American Samoa. To prevent this from happening, we request that you work with the Department of Agriculture to list the Mediterranean Caulerpa taxifolia as a prohibited species under the Federal Noxious Weed Act, preventing its importation, possession or sale in the United States. While a native strain of Caulerpa taxifolia is found in tropical U.S. waters, the Mediterranean clone is a distinctly different seaweed, much larger, more aggressive, and capable of invading both tropical and cooler regions. This invasive clone was apparently introduced into the Mediterranean Sea from the Monaco Aquarium in 1984. It covered roughly one square yard in 1984, spread to over 2 acres by 1989, and now covers over 10,000 acres extending from the shore to depths of over 250 feet. It grows on both rocky and sandy bottoms, from protected bays to exposed capes, and attains great densities, forming monoculture stands whose impact has been compared to unrolling a carpet of Astroturf across the bottom of the sea. In these regions it causes ecological and economic devastation by overgrowing and eliminating native seaweeds, seagrasses and invertebrates (such as corals, sea-fans and sponges). It has harmed tourism, destroyed recreational diving and created a costly impediment to commercial fishing. Allowing the release of this organism into the Mediterranean was an act of environmental mismanagement that threatens catastrophic changes and the loss of biological diversity in one of the world's most valued marine ecosystems. We believe that allowing its importation and sale in the United States is equally ill advised. We further ask that you initiate a review of federal policies and practices regarding the importation and sale of non-indigenous marine and freshwater organisms by the aquarium trade. These practices generally take a "dirty list" approach, in which certain unacceptable species are prohibited and all unlisted species are freely imported and sold. It is in part this dirty list regulatory approach that has allowed the continued importation of the Mediterranean Caulerpa taxifolia clone and other potentially harmful organisms, despite clear evidence in some cases of substantial damage in other parts of the world. Recent, well-documented cases of substantial economic and environmental harm caused by nonindigenous aquatic organisms demonstrate that it is time to move to a "clean list" approach, in which the United States would import only those organisms which evidence indicates will not be harmful. At stake is nothing less than the health of our commercial and recreational fisheries, the growing aquaculture and mariculture industries, and the rivers, lakes and coastal waters of our nation."
(from http://www.mcbi.org/caulerpa/babbitt.html, as cited in Wittenberg & Cock, 2001)

The invasive strain in the Mediterranean can tolerate temperatures as low as 10°C, survive out of water in moist conditions for up to 10 days (e.g. in anchor wells or postal packets from aquarium suppliers), and it can colonise most kinds of substrata including rock, sand, mud, seagrass beds and rhizomes. It has been found at depths from less than 1 m to 99 m deep in the Mediterranean. In eastern Australia (New South Wales) the strain has been recorded to depths of ~10 m, where it occurs mainly on sandy sediments. The invasive strain reproduces asexually (vegetatively) and disperses via fragmentation. Very small fragments can settle and start generating rhizomes (root-like structures). Growth rates are greatest in the summer months (coverage can increase by a factor of 10 in a single summer season).

When 200 m² (spread over 1 hectare) was discovered in an anchorage area off Cala D'Or (Spain) in 1992, this could be only temporarily eradicated (Meinesz 1999). To achieve this the anchorage was closed 2 days after discovery, and the plants were manually removed by divers within a month. Manual removal of re-establishing plants was repeated in 1993, and in 1994 it seemed the eradication had been successful. Unfortunately, it not only reappeared outside Cala D'Or in 1995, but this time was in much larger quantities where manual removal was no longer feasible. The aquarium strain has continued to spread along the northern Mediterranean coasts of France, Spain, Italy and Croatia during the late 1990s, and it was found in Greece and Tunisia by 2000. By this time the alga was covering some 131 km^2 of the Mediterranean seafloor. It is presently reducing the natural habitat for native larval fish and invertebrates, and is threatening several areas valued for their high marine biodiversity (particularly for some species of algae and *Posidonia* beds, which are designated as habitats of European Community interest under EC Annex I, Habitats Directive).

Despite the petition effort to prevent its inadvertent introduction to coastal waters of the United States, the aquarium strain of *C. taxifolia* was discovered in June 2000 by divers working at Carlsbad, about 35 km north of San Diego. These divers were monitoring eelgrass transplanted to restore marine habitat in the Agua Hedionda coastal lagoon near the Cabrillo Power Plant I. Ten patches were discovered, the largest measuring ~20 m by 10 m. Suspected outbreaks in Florida and Brazil were never substantiated). Outbreaks were also discovered in 2000 at temperate locations along the east Australian coast (New South Wales), and subsequently at three locations in South Australia in 2002 (see Box 7, Section 5).

Discovery of the plant in the Californian lagoons near Huntington Harbour led to an almost immediate emergency response involving containment and a rapid decision to eradicate, initially using PVC tarpaulins and chlorine injections. Due to response coordination difficulties including permit difficulties, further efforts were subsequently required to deal with the problem, and regular monitoring was instigated to ensure the eradication measures were being achieved (Anderson 2002). *C. taxifolia* was also first discovered in New South Wales (NSW) in 2000. Here it was found in estuarine waters near Port Hacking (30 km south of Sydney) in March 2000. As of October 2003, it is now known from eight NSW coastal lakes and estuaries (from Lake Macquarie south of Newcastle and Pittwater near Sydney to Burrill Lake, Narrawallee Inlet and Lake Conjola on the south coast). The degree of invasion has varied from place to place, ranging from small, isolated patches to dense beds covering many hectares. Australian research on the impacts of *C. taxifolia* on native flora (seagrasses) and fauna (invertebrates and fishes) is in its early stage, and the full significance of the threat posed by the cool-water strain remains unclear. The extent of the invasions negated the option for an immediate eradication program, so focus was placed on control and research.

There is still uncertainty about the source of the Australian outbreaks, but genetic evidence suggests the various populations have come from multiple sources. It also appears that the Mediterranean 'aquarium strain' is genetically similar to native Queensland populations of *C. taxifolia*. It is therefore possible that *C. taxifolia* taken originally from Queensland was cultured in aquaria around the world over many years (it has been available from aquarium suppliers via internet ordering services). Despite the uncertainly of the precise origins of the invasive Australian populations, they have spread in cooler areas where this species was not previously recorded, as per the situation in the Mediterranean.

Funds for investigating the ecology and possible control of the seaweed in NSW became available in 2002. Since then, NSW Fisheries has been conducting an extensive research and control program in affected estuaries. Regular surveys have found that many of the beds are highly dynamic and may expand, decrease in size or disappear over relatively short periods of time for no obvious reason. Several NSW research projects are ongoing, with some examining its habitat value for fish and invertebrates (compared to native seagrasses), its survival under different physical conditions, and its growth and dispersal via fragmentation.

The NSW research has also included trials of various control methods, including habitat modification by the application of some 1,000 tonnes of salt (NaCl) to raise water salinity for treating more than 4 hectares of the weed. These works and other actions (closures to certain types of fishing activities, public education, etc) appear to have prevented the further spread of *C. taxifolia* to new estuaries, and have assisted the removal of large amounts from some waterways. However, the total area currently covered by the existing *C. taxifolia* beds in NSW is considered too large to allow comprehensive treatment of all areas by present methods, and its permanent eradication from these waters may not be feasible. For this reason, NSW Fisheries is developing a Control Plan. Specific goals of the Control Plan will probably include the following (Ian Peebles, pers. comm.):

- Coordinate management with all relevant local and state government agencies.
- Prevent the further spread of *C. taxifolia* within and beyond infected estuaries.
- Prioritise control locations and options for cost-effective use of available resources.
- Increase community awareness and understanding of *C. taxifolia* impacts and their role in the strategies to help prevent its spread and mitigate its impacts.
- Mitigate impacts of existing *C. taxifolia* beds on biodiversity and fisheries productivity.
- Increase understanding on the spread and impacts of *C. taxifolia* in NSW waters to help improve initial control measures.
- Ensure future changes to the control plan are underpinned by reliable data and careful evaluation.

4.2 ZEBRA MUSSEL - *DREISSENA POLYMORPHA*

This case history is drawn from descriptions by Orlova & Nalepa (1999, 2002: http://www.zin.ru/projects/invasions/gaas/drepol.htm and Galil (2003), plus sources and links to the evolution, biology, impacts and spread of zebra mussels (Appendix A).

The zebra mussel family contains several genera apart from *Dreissena*. However, based on their biology, environmental preferences and patterns of natural and human-assisted dispersal and propensity to spread, all their species and subspecies form two functional groups: a euryhaline and so-called ‘fresh water’ group, and a mezohaline ‘brackish /marine water’ group[12].

[12] The three species in the brackish group [e.g., *Dreissena (Pontodreissena) rostriformis*, *Dreissena (Dreissena) caspia*, *Dreissena (Dreissena) elata*] were limited to areas with constant salinity of 8-13% in the Caspian and Aral Seas up to the 1960-70s. Expansion of *Mytilaster linneatus*, a bivalve with the same byssate-attached, filter-feeding lifestyle that first appeared in the Caspian Sea in the 1920s, led to a decline in these taxa. The decline, followed by the catastrophic desiccation and salinization of the Aral Sea in the 1960s-1970s caused a rapid constriction of areas inhabited by *D. rostriformis* in the Caspian and the complete extinction of *D. elata* and *D. caspia* in both the Caspian and Aral basins. Thus these species inhabited) the native basins of the Caspian and the Aral Seas until 1970s and they have never been found anywhere else.

Both *Dreissena (Dreissena) polymorpha* (zebra mussel) and *Dreissena (Pontodreissena) bugensis* (quagga mussel) are in the euryhaline group. Their fossil records extend 10-11 million years to estuaries of the central Paratethys, and their contemporary native areas comprise the estuaries and coastal waters of the Ponto-Caspian and Aral Sea basins. The spread of D. polymorpha to other European localities as a result of unintentional introductions has been reported since the eighteenth century. The first invasion of *D. bugensis* (from estuaries of the Black and Azov Seas into artificial channels and reservoirs in Ukraine) were first reported in the 1960s.

New invasions have been reported since the late 1980s, with *D. polymorpha* recorded in brackish-water areas of south-eastern Gulf of Finland (near St.-Petersburg) and further northward along the Finnish coast in 1995. It has since been detected in the Ebro Delta on Spain's Mediterranean Coast. *D. polymorpha* was first reported in North America in 1988 and in Ireland in 1994 (Shannon catchment). It rapidly expanded in both countries, reaching Northern Ireland (UK) via the shared Erne River catchment and along the Mississippi system by river barge and boating traffic, a spread accompanied by catastrophic impacts on local ecosystems as well as fouling-prone infrastructures.

Until the 1960s the distribution of *D. bugensis* appeared limited to some rivers and estuaries of the Black and Asov Seas, but it is now common in many rivers, reservoirs and streams of the Black Sea drainage. It also co-occurs with *D. polymorpha* in the Volga River, Volga delta, and the low salinity region of the northern Caspian Sea (up to 2-3%). It was first reported from North America in 1989 where it now co-occurs with *D. polymorpha* in many localities.

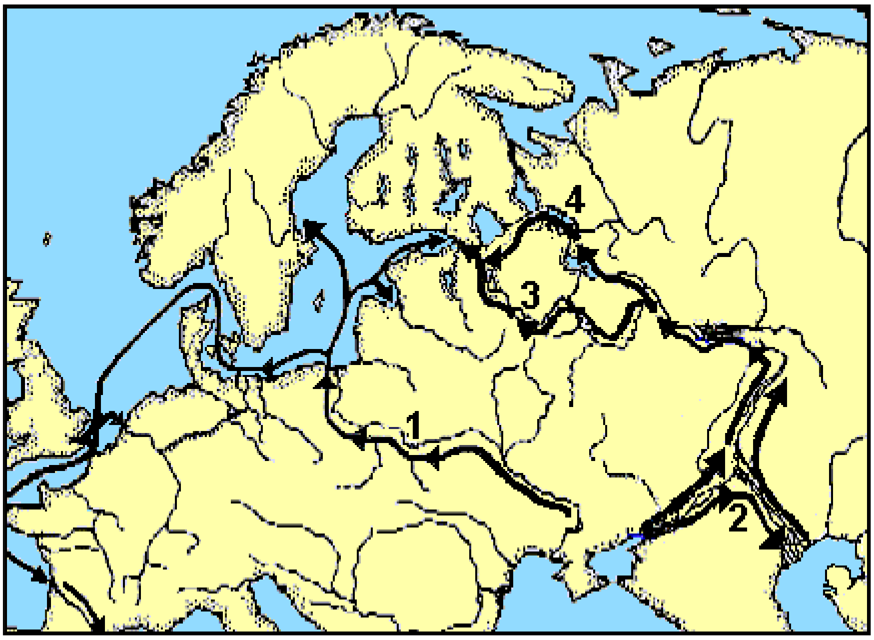
The depth distribution of *D. polymorpha* varies from 0.1 m to 50-60 m and depends on the presence of suitable substrates, suspended food (seston), wave exposure and ice abrasion. Abundant *D. polymorpha* populations have been recorded on reeds, flooded forests and submerged aquatic plants, mollusc shells and valves, and on crustaceans. Very high abundances can occur on artificial substrate (e.g. over 4 million per m^2 on power plant water pipes). The lower thermal tolerance range is ~0°C for adult survival, 5-10°C for feeding and growth, and 12°C for spawning. The higher thermal limit for adult survival, as reported from experiments as well as power plant cooling pipes, is 30-32°C.

In the Baltic Sea and Gulf of Finland, *D. polymorpha* usually inhabits waters from entirely fresh to 6-7‰. Peak larval abundances are associated with 0.3-0.7‰ salinity. Adult are usually present where oxygen saturation is in the 70-90% range, but will tolerate levels to as low as 50% saturation. They can also tolerate continual air exposure for 5-6 days.

Navigation by a wide range of commercial and recreational vessel types is considered the main vector accounting for the range expansions of the zebra mussel, with the transport of *D. polymorpha* from native areas to geographically remote basins in Europe accomplished primarily by shipping along human-made inter-basin canals and channels. Temperate lakes, rivers, reservoirs, estuaries and coastal zones of brackish seas are potential areas for future range expansions. Areas where the zebra mussel establishes rapidly become donor areas for further invasions. Its ability to rapidly colonise new areas is related to its relatively high tolerance to water temperature and salinity changes, rapid growth and life cycle, and reproductive prowess. Dreissenids are unisexual with populations having equal proportions of males and females. Unlike other freshwater mussels, Dreissenids have pelagic larval stages similar to marine and brackish-water bivalves, which aids dispersal.

While *D. polymorpha* achieved its pre-Holocene range along rivers, this and other natural vectors are not considered responsible for the major expansions noted since 1803. Human-mediated mechanisms aiding *Dreissena* dispersal have been considered almost unlimited (Carlton 1993), particularly those associated with transportation of water (e.g. containing the free-living larval stages), or damp or submerged objects with attached adults and juveniles, within and between catchments and basins. In the case of vessel mediated transfers, it is widely agreed that development and increasing use of the following inter-basin connections in the 19th and 20th Centuries accelerated its range expansion (the numbers refer to Figure 1):

- The Dnepr-Nenam system (1; via the Oginskii channel between the Jasel'da and Shara Rivers; pre-1800) – greatly assisting the spread of *D. polymorpha* from the Black Sea basin into Western Europe.
- The Volga-Don channel (2) - facilitating the exchange of *D. polymorpha* and *D. bugensis* between the Black and Caspian Sea basins.
- The Vishnevolozkaya system (3) and Volgo-Baltiisky channel (4) - assisting *Dreissena* dispersal from both the Caspian and Black Sea Basins.



(modified from Orlova & Nalepa 2002)

Figure 4: Canal- and ship-mediated pathways of *Dreissena* mussels in Europe

It is widely believed that the Oginskii canal stimulated the transport of *Dreissena* to the Neman River, where it reached Kursk Bay in 1803. In 1824 it was found in England (London; Thames River) and Germany (Potsdam); in 1827 in Holland (mouth of the Rhine River); in 1843 in Denmark (Copenhagen); 1855 in Frankfurt (Germany); in 1868 in Regensburg (on the Danube); in 1896 in Poland (Szczecin Bay); and in 1940-42 in Sweden (Stockholm). Most of the Baltic Sea populations probably originated from the Black Sea basin via this vector, or possibly via waterways connecting the Caspian and Baltic Seas (i.e. Vishnevolozkaya system and Mariinsky channel). The Volgo-Baltiisky waterway (opened for navigation in 1964) provided an additional route for Ponto-Caspian populations and other biota to enter the eastern part of the Baltic Sea (Figure 1).

In the case of North America, zebra mussel larvae are believed to have arrived in 1988 in the ballast tanks of a transatlantic ship which were discharged into Lake St. Clair, between Lakes Huron and Erie. Its subsequent and extraordinarily rapid spread throughout the Great Lakes and eventually a major proportion of the Mississippi River drainages within the first few

years of its arrival, has been linked to the large barges which trade up and down the large navigable waterways such as the Mississippi, Ohio, Tennessee, and Arkansas rivers. Since 1993 their expansion has slowed, with their appearance the Missouri - the main north-west branch of the Mississippi system - not occurring until 1999 (Figure 2).
(www.nfrcg.gov/nas/zebramussel/missouri.htm).

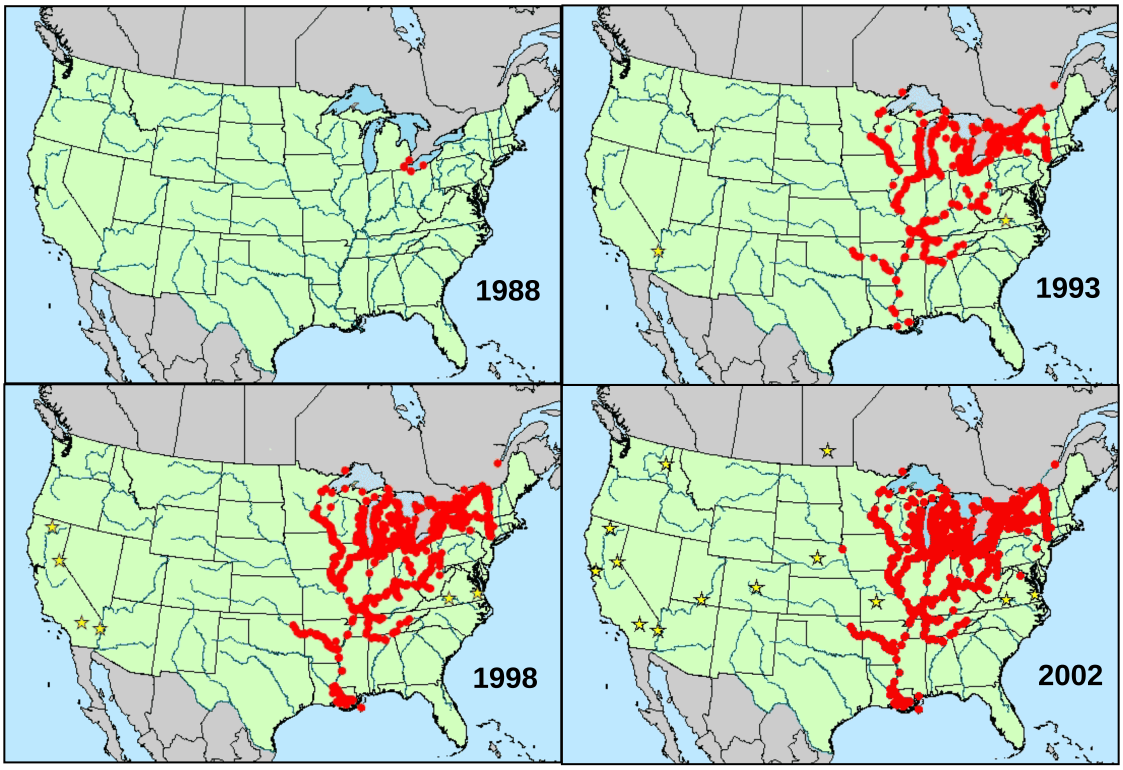


Figure 2: Annual distributions of *Dreissena polymorpha*, showing the initially rapid barge-mediated expansion phase (1988-1993), followed by infill and sporadic extensions by trailered boats and fishing gear.

However within this range they have continued to infest many new locations, especially into hundreds of unconnected small lakes within the States bordering the Great Lakes as a result of overland transport on trailered recreational fishing boats and dinghies. They have also been appearing in isolated water bodies in the central and western States (Figure 2), again as a result of overland movements of boats and fishing gear.

The mussels reach high densities and are efficient filter-feeders, removing phytoplankton and outcompeting zooplankton, native mussels and fish and thus disrupting natural food webs. By adhering to the shells of the native mussels in densities up to 10,000 zebra mussels per single native adult animal, the smothering effect interferes with the natives' feeding, growth, respiration and reproduction. Native mollusc populations have therefore been crashing within four years of zebra mussel incursion. Unchecked by local predators or parasites, its invasion of the Great Lakes and Mississippi basin aquatic systems has overwhelmed the native freshwater mussel fauna which is now facing a massive extinction (up to 140 species). Apart from the large-scale ecosystem changes, the US Fish and Wildlife Service estimates its economic impact exceeded US$5 billion in damages by 2002.

Since the zebra mussel's arrival, the Great Lakes Sea Grant Network, State of Wisconsin, US Geological Survey and other agencies have implemented mussel monitoring public education and efforts including signage material for these and other invasive species including the European watermilfoil (Box 3).

Box 3: Guidelines Codes and Boat Ramp Notices provided for Trailer Boats in the State of Wisconsin (United States)
(from: http://www.seagrant.wisc.edu/outreach/nis/Prevent.html)

Boaters and anglers need to take special care not to spread zebra mussels or other invasive species from one water body to another. By taking just a few simple steps you can help prevent the spread of these organisms into your favourite lakes.

Drain bilge, live well, bait well and motor water from your boat before leaving the ramp.

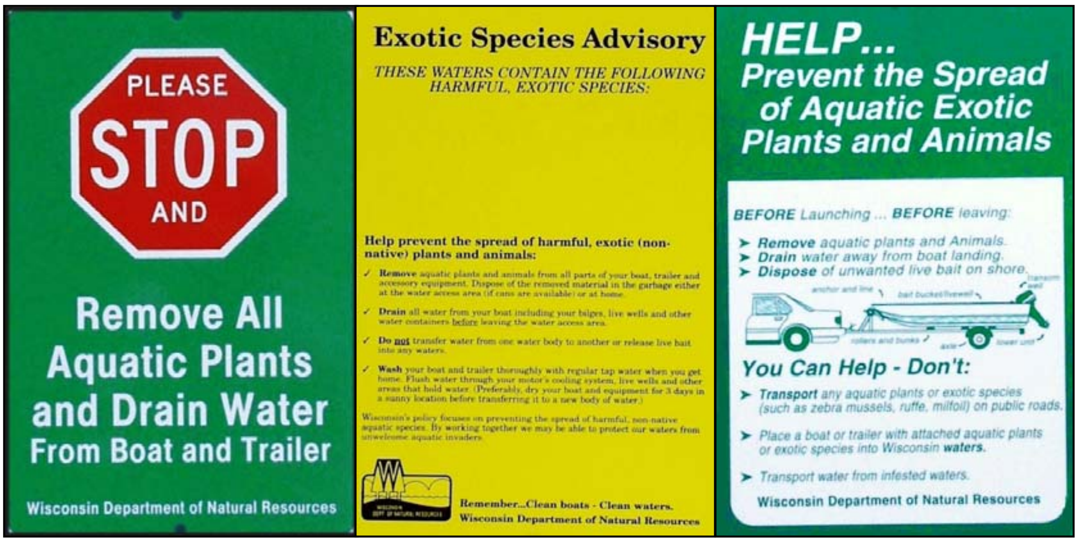
Clean weeds off the motor, boat and trailer. Run personal watercraft out of the water for 5 to 10 seconds to clear the intake chamber of weeds.

Dispose of live bait in the trash, not in the water.

Dry your boat for 5 days, or

Wash your boat and trailer with a high pressure sprayer or hot water such as at a car wash.

Help prevent the spread of non-indigenous species. Perform these actions every time you use your boat, whether you know the water to be infested or not. Share the information with your friends to help preserve Wisconsin's waters. Watch for these signs posted at boat ramps:



The **'Stop'** sign: may be posted at any water, reminds boaters to remove weeds, water and other potential sources of nonindigenous species from their boat and trailer.

The **'Yellow'** sign: posted at infested waters.

The **'Help'** sign: contains generalized information on preventing the spread of aquatic exotics.

REGULATIONS ON EURASIAN WATERMILFOIL IN WISCONSIN:

It is unlawful in the State of Wisconsin to: (a) transport aquatic plants, including Eurasian watermilfoil or other prohibited species on public roads; (b) place a boat or trailer with attached aquatic plants or prohibited species into Wisconsin waters.

At sites where local population densities have caused considerable nuisance and costly fouling and cleaning problems (>US$200 million), various manual scraping, abrasive blasting and high-pressure water jets have been successful for their temporary removal but have proved expensive and time consuming. Screens and filters have been used to prevent uptake of mussels through pipes in hydroelectric facilities. Water heated to temperatures above their thermal tolerance (>40º C) has been used to destroy newly settled mussel spat within pipe work, while cathodic protection and UV irradiation have been also been used to suppress zebra mussel settlement. Where cleaning can be undertaken in confined areas that can be isolated from natural waterways, various organic and inorganic chemicals have provided versatile, relatively simple and more cost-effective ways to deal with established infestations and prevent new ones (Boelman et al 1997, Specher & Getsinger 2001). However, since these biocides are not harmless to native aquatic biota, their use has been restricted to internal piping and other types of fully closable systems.

Biocontrol experiments using a generalist predator (the blue crab *Callinectes sapidus*) indicate that increased populations of this crab might be capable of reducing zebra mussel abundance (Boles & Lipcius 1997). Another biological control agent (a selectively toxic microbe, the bacterial strain CL0145A) may also hold promise for environmentally safe control of zebra mussels, based on results from initial laboratory and field trials (Galil 2003).

4.3 BLACK-STRIPED MUSSEL - *MYTILOPSIS ADAMSI (SYN. M. SALLEI)*

This case study summarises the present introduced range of the black-striped ‘false’ mussel, *Mytilopsis adamsi* (syn. *M. sallei; Congeria sallei*) and the eradication and follow-up prevention responses ,taken by Australia after its detection in Darwin marinas in March 1999.

M. adamsi is a small, delicate bivalve with very high fouling capabilities (i.e. mass settlements and rapid growth on hulls and in pipework that interrupts cooling water flow). It is native to the tropical and subtropical western Atlantic (from the Gulf of Mexico to Colombia) and has considerable fouling abilities to cause serious economic and environmental damage in infested areas. The black-striped mussel has spread into the Indo-Pacific region via hull fouling, with populations occuring in sheltered harbour waters in a wide range of locations including Fiji, Hong Kong, India, Indonesia, Japan, the Philippines, Singapore and Taiwan (e.g. Jakarta, Manila, Mumbai, Surabaya and Visakhapatnam). Its wide salinity tolerance range allows it to survive transits through the Panama Canal, which first opened to shipping traffic in 1914. It is believed to have invaded Fiji prior to 1950, then Indonesia and India (ca. 1967 in Navy docks at Visakhapatnam and subsequently Mumbai). It has since been found in Japan and Taiwan (1970s) and Hong Kong (early 1980s).

The mussel fouls hard substrates, vessels and structures, causing extensive economic damage and may out compete native marine species, smother native bivalves and impact shellfish aquaculture. In its preferred inshore, low estuarine habitats, introduced populations are capable of forming mats 10-15 cm thick. Despite their small maximum size (2.5 cm in length), the mussels mature after four weeks (ca. 1 cm), with females producing up to 50,000 offspring that can settle on almost any surface to the eventual exclusion of all other life. After four weeks of growth the young mussels can form 100 kg of fouling material on hulls, chains, ropes, nets, mooring buoys, piles, floating pontoons, inside pipes or other hard surfaces. Seawater intakes for industrial plants, vessel cooling system intakes and mariculture facilities are particularly vulnerable.

In 1999 large populations of this mussel were discovered in three separate lock-gate marinas in Darwin, northern Australia. The discovery was made by a port baseline survey for introduced species, and its relatively early detection permitted a successful eradication effort. *Mytilopsis sallei* It is believed to have been spread by hull fouling of commercial fishing vessel, international cruising yacht or possibly another recreational vessel, with the initial incursion probably from a Indonesian port rather than Fiji or directly from the Caribbean.

Recognizing the potential economic and ecological impacts of the *M. sallei* infestation, the Northern Territory Government (NTG) implemented an immediate containment program and quickly secured the support of the Federal Government for the eradication effort. The gated marinas were closed and the enclosed water, vessels and submerged surfaces were treated with 170 tonnes of sodium hypochlorite and 3 tonnes of copper sulphate, which eventually killed all the mussels after approximately 15-18 days. The internal pipework of 420 exposed vessels was treated with a combination disinfectant detergent (many had reached other ports having left the marinas before the discovery). Exposed vessels located and inspected outside the marinas and found to be carrying the mussel were hauled out onto a hard stand for at least a week. The main operation took over four weeks, plus several intensive follow up inspections on surfaces and vessels in and beyond the marinas in the same year. The latter surveys of other marinas and harbours along the northern Australia coastline were extensive and found no live mussels (Bax 1999). Approximately 270 people were involved and the equipment, logistical and consumable costs amounted to AUD$2.2 million (excluding labour). Potential damage and costs to marine infrastructure, fisheries, mariculture operations and coastal ecosystems would have been far higher if the mussels had been allowed to spread to other harbours and open coastal systems where existing technology offered little chance of eradication. Several factors contributed to the success of the eradication campaign, including:

- its early detection;
- a rapid response;
- whole of government support;
- the ability to isolate the marina basins from the local marine environment by double lock gates;
- substantial community support;
- the ability to track exposed vessels;
- a pre-existing legal capacity via Fishery and Quarantine legislation to enter, seize or destroy private property.

Pre-existing information on suitable treatments for related taxa was also available (Bax 1999, Ferguson 2000), as *Mytilopsis* is closely related to the dreissenid zebra mussels (*Dreissena polymorpha*) which had invaded North American waterways during the 1990s (Section 4.2). Pertinent biological and eradication information for rapidly mounting a suitable eradication programme could therefore be rapidly accessed via the Sea Grants National Aquatic Nuisance Species Clearinghouse (http://cce.cornell.edu/seagrant/nansc/SGNIS). While the collateral damage to native plants and animals within the treated marinas was high (all biota was killed), this was temporary and restricted to these artificial marine habitats.

At the end of the eradication campaign a national taskforce was established to evaluate the response (Ferguson 2000). It concluded that other marine invaders could be equally devastating, so it would be worth Australia having the same ability to mount a rapid response against these organisms. CSIRO subsequently assembled a set of ‘rapid response options’ for marine taxa considered most likely to pose a significant threat to Australia (http://crimp.marine.csiro.au/reports/publications.html). The review also facilitated development of a national marine NIS database (National Introduced Marine Pest Information

System; NIMPIS; Appendix A). NIMPIS contains an interactive 'rapid response toolbox' (Section 5.3) providing information on targeted pest species, eradication attempts, physical and legal constraints and available experts and suppliers (the latter in Australia only). A hazard analysis module is planned to help response decision-taking.

A mussel surveillance monitoring programme has been implemented by the NTG which documents water quality and monitors for the arrival of marine pest species using mussel spat settlement collectors at sites in the marinas and in the outer Darwin harbour area. The detachable plates and ropes of these settlement devices are collected on a regular basis and screened for the presence of pest species. This operation is managed by Aquatic Pest Management Team of the NTG's Department of Primary Industry and Fisheries (DPIF)

Because *Mytilopsis* sp. is well established at many Indo-Pacific ports used by international cruising yachts and foreign fishing vessels, the DPIF has sought the co-operation of all international arrivals wishing to enter Darwin's lock-gate marinas. Any of these vessels which cannot demonstrate that its hull was anti-fouled in Australia is required to undergo a (free) hull inspection and internal seawater system treatment. Arrivals previously anti-fouled in Australia have their internal seawater systems treated prior to being permitted entry.

Since 1999 the DPIF has been inspecting, and in many cases treating, an average of 20 vessels per month. In the first two years, 364 yachts, 38 fishing trawlers and 35 apprehended 'suspected illegal-entry vessels' (SIEVs) were inspected. The value of the inspection and treatment strategy has been demonstrated several times. One vessel denied a marina entry (having spent the previous six months in Indonesian waters and not anti-fouled since its return to Australia) had four bivalve species in the strainers of its internal seawater system. Of the four species, two appeared to be *Mytilopsis*, one was the Asian green mussel (*Perna viridis*; Section 4.8.4.2) and the fourth was possibly another non-native species (a *Musculista* sp. bag mussel; http://coburg.nt.gov.au/dpif/fisheries/environ/unittext.shtml).

4.4 FLUCTUATIONS OF ASIAN MITTEN CRABS -*ERIOCHIER AMURENSIS*

The Asian mitten crab is native to the rivers and estuaries of China and Korea along the Yellow Sea. The young crabs grow and develop in freshwater before migrating to the sea to reproduce and die. They burrow into river banks and can cause accelerated erosion and slumping. High densities of adult crabs during the migration period can also block water intakes to irrigation and water supply schemes. They carry a lung fluke that infects humans. They prey heavily on fish and eels caught in commercial fishing traps placed in estuaries.

Chinese mitten crabs can be translocated as larvae and postlarvae in ballast water or as young adults in a vessel's seachests and other niches. Because it is a prized food source in some Asian regions it has also been deliberately transferred to some countries, including illegal translocations to US Pacific coast ports including San Francisco Bay.

The first discovery of this crab in Europe was in Germany in 1912. By the 1920s the population had boomed to massive size owing to frequent annually conducive reproduction and recruitment conditions. During these mass occurrences, including those in and near Hamburg during the 1930s and 40s, it caused damage to river banks, dykes and other coast protection and harbour installations. It was first discovered in the United Kingdom in 1935 (River Thames).

More severe winters experienced in north Europe from the mid 1940s to the early 1970s, coupled with other factors including decreased water quality, caused the north German population to decline to the point where few were seen in some years. However the return to milder and wetter winter and spring periods in the 1980s-90s led to a resurgence. Similar cycles of population size have been reported for other introduced mitten crab populations, including the Netherlands and the United Kingdom, where high population numbers occurred after a drought in 1989-1992 (Eno *et al* 1997, cited in Williamson *et al*. 2002).

4.5 IMPACTS OF NORTH PACIFIC SEASTAR - *ASTERIAS AMURENSIS*

The Northern Pacific Seastar (*Asterias amurensis*) is native to the north Pacific region, with its natural range extending from Korea, Japan and the Kamchatka Peninsula of Russia to Alaska. It has wide temperature and salinity tolerances, Population densities easily exceed those recorded in its native range and is a voracious predator of a wide range of other species including clams, mussels and sea urchins.

It was first introduced to Australia (Hobart) in the early 1980s either as larvae released with discharged ballast water or by hull fouling, and probably via woodchip carriers or other cargo ships arriving from Japan. It was initially restricted to the Derwent estuary (Tasmania's major port) until 1998. Natural spread from the Derwent system is believed to have been restricted by the local pattern of estuarine circulation, but it has since ‘port-hopped’ to Port Phillip Bay (~600 km), which contains the State of Victoria's major ports and fishing harbours, including Melbourne and Geelong. Genetic tests indicate that the transfer across Bass Strait was most likely from the Tasmanian population via hull fouling or ballast water rather than other possible vectors (e.g. mussel lines moved between mariculture facilities, or trawl nets).

Populations of the Northern Pacific Seastar can become extremely dense in both its native and introduced range. Populations in the Derwent estuary have grown to the point where it is the dominant invertebrate predator of some benthic communities. In Port Phillip Bay (Victoria) the population reached approximately 30 million within two years and the total Australian population could be as high as 120 million. Its impacts on marine biodiversity and commercial mollusc fisheries have been profound, as it is a major pest to shellfish farming and wild harvest industries. It can eliminate all clams and mussels in an area (densities of one seastar per square metre were enough to eliminate over 90% of the native biomass in Tasmania), and industry viability has been threatened. If inadvertently introduced to New Zealand, this species would have a significant economic impact on its aquaculture and fishing industries as well as on shipping.

To minimise the risk of a ship-mediated invasion to New Zealand, special precautions have been taken, including the complete ban on ballast tank discharges if all or part of the tank water had been uplifted at the infected Tasmanian and Victorian ports. The New Zealand shellfish industry is worth NZ$315 million in export earnings, and it has been predicted that this valuable stock could be reduced by 10-50% with commensurate economic and social impacts, if the Northern Pacific Seastar became widespread in New Zealand, plus a further $500,000-$1million annually for increased surveillance costs. In fact any discovered incursion would entail immediate domestic and international shipping controls to limit further spread which have been estimated to cost $1 million annually per incursion. Costs to international shipping could be $2million annually due to the management actions that would need to be imposed to their reduce spread. Impacts and costs to customary harvest values by New Zealand’s Maori interests have not been estimated.

Manual removal by divers is ineffective as a control method for large populations. Community divers removed 30,000 seastars from around the Hobart wharves on two occasions in 1993 (possibly 60% of the animals from an area that was a fraction of the total occupied area). This exercise involved the removal of seastars from a 300 x 20 m area, yet the next month four times as many were collected.

Baited traps provide a more cost effective alternative to control chronic infestations, although when densities are reduced these can attract seastars from outside the control area. Apart from physical removal and trap testing, no other attempt has so far been made to reduce *A. amurensis* numbers in Australia.

Dredges and trawls have been used in Japan to control the seastar prior to seeding an area for shellfish aquaculture, but associated environmental damage has been considered excessive and inappropriate for previously unfished areas. Non-specific chemicals, principally quicklime, have been used to locally control seastars on shellfish beds, but the collateral damage to native biota is high. Non-specific physical and chemical control may have a role in local control of seastars around aquaculture farms, but sustainable control of the seastar population will require a highly specific biological control agent that can be widely dispersed throughout the population. Possible biological control agents studied have included sporozoans, dendrogastrids, eulimid gastropods, and the highly contagious parasitic ciliate *Orchitophyra stellarum* which causes male infertility in the Japanese populations of *A. amurensis* but may parasitise native seastars.

If trawled individuals of the founder population had been recognised as an unfamiliar seastar in the Derwent Estuary in the early to mid 1980s (i.e. when it was small and capable of being removed by a targeted and intensive program involving diver removal, trapping, chemical dosing and regular follow-up surveys), it is possible the incursion could have been successfully eradicated.

4.6 GIANT MEDITERRANEAN FANWORM - *SABELLA SPALLANZANII*

The Mediterranean giant fanworm, *Sabella spallanzanii*, has been introduced principally via hull fouling to port waters and harbour embayments in Brazil, Java (Indonesia), Melbourne (south-east Australia) and several ports in south-west Australia. This fan worm develops large dense clusters which foul hard substrates, vessels, navigation aids and other man-made structures. In years following major successful settlements, thick dense carpets and mats up to 100 specimens/m^2 can develop. These are feared to out-compete native suspension feeders for food, smother native bivalves and impact shellfish aquaculture and fisheries.

The ability of *S. spallanzanii* to regenerate damaged body parts precludes use of dredges for large scale removal (it is possible that scallop fisheries may have contributed to the rapid spread of the fanworm in some areas by their discard of fan worm fragments overboard). *Sabella spallanzanii* was successfully controlled in Eden Harbour, NSW, where it was manually removed by divers (Appendix A). However, physical removal is feasible only if fan worms are detected in small areas before a successful spawning and recruitment occurs.

Introduced populations of *Sabella spallanzanii* have also demonstrated swings in densities between years, including the initially high levels first discovered in Cockburn Sound (near Fremantle) in Western Australia in the 1994 (but thought to have arrived much earlier, followed by a decline by 2000/2001 that was presumably caused by variations in factors influencing its reproductive or settlement success (C. Astbury WADF, pers. comm.). The species had also ‘port hopped’ to establish at locations within the three southern ports of Western Australia, i.e. Bunbury (at least 1993), Albany (possibly as early as 1965) and Esperance (probably before 2001) (Clapin & Evans 1995; C. Astbury WADF, pers. comm.).

In 1993, the *Kingfisher* dredge had been recorded carrying many worms matching the description of *S. spallanzanii* on its hull in Bunbury Harbour. This dredge was often towed between Fremantle, Bunbury and other Western Australian ports (Clapin & Evans 1995). Other evidence from the US shows dredging activities have secondarily distributed non-native species from their initial point of introduction (Robinson & Wellborn 1998; Rosenfield & Mann 1992 cited in Environment Australia 2002). It has therefore been concluded that dredges and barges have been a significant factor in spreading the European fanworm up and down the Western Australian coastline via hull fouling (Cappo *et al*. 1998; Environment Australia 2002).

4.7 CARIBBEAN TUBE WORM - *HYDROIDES SANCTAECRUCIS*

This case study describes the discovery, response and current outcome of a recently established but unsuspected introduced fouling species in an Australian port, and is drawn from the personal observations, fieldwork and unpublished accounts collated by the report authors.

The native range of the fouling tube worm *Hydroides sanctaecrucis* (Polychaeta, Serpulidae) is the Caribbean region, from the Gulf of Mexico to Venezuela. It was discovered to have established in the tidal and seasonally estuarine creeks of Trinity Inlet, Cairns (north Queensland) in May 2001. Although this species had formed relatively large and conspicuous fouling colonies, it is very similar in appearance and fouling habit to species of the same genus already in Australia (i.e. *Hydroides elegans*, *H. ezoensis*, etc) and thus had not been paid any attention. Its specific characteristics, which include a cross-shaped marking on the 'cap' (operculum) are also too small for the naked eye.

Its discovery was by laboratory identification from hull fouling samples sent to a marine taxonomist who was familiar with the *Hydroides* genus. These samples had been taken during a visual survey of slipped Australian naval vessels that had returned to Cairns from East Timor in February 2001. The intent of the survey was to check for unwanted non-native mussels such as *Mytilopsis adamsi* and *Perna viridis* (Section 4.8.4.2) and the condition of the anti-fouling coatings. Following its discovery in the sample, a delineation survey was undertaken of ten sites on 25 June 2001:to determine the extent of its presence in Trinity Inlet. High densities were found colonising artificial and natural hard substrates at seven of the ten sites, almost all in the lowest intertidal to shallow subtidal zone. Coverages were typically in the 5-75% range of 1 m^2 sampling quadrats. They were also highly abundant on a moored fishing vessel (MV *Wing Sang 108*) previously seized by Australian Customs.

It was therefore concluded that a likely cause of the incursion was via rapid growth, maturation and massive spawning of the worms fouling this vessel following its arrival in 2000 (see Section 4.6). However there were other vessels that could have introduced the species as early as January 1999. The pathway and arrival date are unclear, as there is no port survey information to confirm likely source port/s, and multiple sources are possible (CRP).

The lead agency for dealing with marine species incursions in the State of Queensland is the Queensland Environmental Protection Agency (QEPA). Other agencies involved during the initial response were the Introduced Marine Pest Group of the CRC Reef Research Centre at Townsville (CRC), the Cairns Port Authority (CPA), the Defence Science and Technology Organisation (DSTO) and the Australian Museum (Sydney).

It was recognised that *H. sanctaecrucis* had the potential to exert ecological and economic impacts via continued dense settlements producing competitive and nuisance biofouling on both natural and artificial submerged hard substrates. However there was no information as to its ability in the Indo-Pacific range to adversely alter littoral ecosystems and species assemblages by space and food competition. Members of the genus are well known to tolerate low level copper concentrations, including an ability to foul cupro-nickel alloys (bronze propeller bosses, blades and blade studs, log probes, external pipework fittings, etc) as well as slow-release copper-based antifouling paints. Such settlements shorten the anti-fouling life-span and effectiveness. Other potential economic impacts could include the increased costs of cleaning fouled surfaces, increased drag and fuel costs for uncleaned vessels, possible blockages to seawater cooling systems, and fouling of mariculture equipment.

Because *H. sanctaecrucis* was discovered to have already colonised a wide range of natural and artificial substrata, QEPA deemed it was established and eradication attempts were not worth undertaking. A public education/awareness brochure outlining the risks of transferring introduced fouling taxa, including this species, was published and distributed with QEPA contact details, and information letters were sent to port users and stakeholders including slipway operators in July 2001. During this month a biofouling/antifouling workshop was held in Cairns (and subsequently at other Queensland coastal towns).

Since November 2001 densities and distribution of *H. sanctaecrucis* in Trinity Inlet have continued to be monitored by CRC during the course of other marine species survey work for CPA and QEPA. By 2003 it had increased its spatial distribution within Trinity Inlet and it remains well established, occupying a range of hard substrate including mooring buoys, vessel hulls and pylons. While it has achieved a wide distribution inside the Port of Cairns it has not become the predominant organism on fouled structures. In fact overall densities in 2003 on hulls and other artificial substrates appeared to be less than in previous years.

Expenditures by QEPA, DSTO and CPA on the initial responses were relatively small and have never been compiled. No information has been collated to determine if there have been increased cleaning costs of fouled vessels and infrastructure. It continues to remain treated as an uneradicable introduction by QEPA, and there is no specific control or containment plan. Its eventual appearance in another Queensland or other State port may trigger revaluation of its status and decisions taken to date.

4.8 EDIBLE SPECIES INTRODUCTIONS

The following cases demonstrate the risk of importing diseases and hitchhikers with edible species (4.8.1), describe the first successful eradication of an oyster pest (4.8.2), and provide contrasting perceptions and responses regarding the need for controlling introduced edible species in Australia, Europe, New Zealand, and South Africa (Sections 4.8.3 - 4.8.5).

4.8.1 Pathogens and Hitchhikers on Oyster Shipments

For more than 150 years, several species of oyster (especially *Ostrea edulis*, *Crassostrea gigas* and *Crassostrea virginica*) have been transported in large numbers around the world for mariculture purposes in coastal waters remote from their native ranges. Despite their potential economic value, the oysters themselves can exert harmful effects (in Australia the Pacific oyster *Crassostrea gigas* is considered a pest species since it outcompetes Sydney rock oysters and other native *Saccostrea* species; Section 3.2). It is also interesting that *C. gigas* arrived in New Zealand over 30 years ago via an unintentional introduction from Hiroshima, as a fouling organism of barges and extension works to the Auckland Harbour Bridge

(Dinamani 1971). It has since naturalised to become the dominant cultured oyster in New Zealand.

Many organisms also travelled with them: parasites, commensals and epibionts (the latter attached to or living on rough oyster shells or among oyster clumps), plus oyster predators, pests and other organisms carried in the mud, water and other materials packed with the oysters. Oyster shipments may have also introduced toxic, red tide dinoflagellates or novel strains of cholera but this remains unproven. Examples of damaging shellfish diseases and other pests transferred via oyster shipments include:

- Oyster diseases MSX (*Haplosporidium nelsoni*) and microcell disease (*Bonamia ostreae*)
- Sponges (that grow into and weaken oyster shells) and flatworms
- A parasitic copepod of oysters that reduces their size, taste and marketability.
- Oyster drills: predatory marine whelks (gastropod snails) which bore into oysters and other bivalves.
- Slipper shells and seaweeds (these foulers compete with oysters for space).
- Introduction of *Undaria pinnatifida* (Japanese brown kelp) into Europe. This species was first recorded in Europe in 1971 in a French Atlantic coastal lagoon, and is considered to have been accidentally introduced with Japanese oyster imports as well as deliberately in 1983 for a mariculture enterprise (Section 3.3).

Of the other >230 non-native species found in San Francisco Bay, many are considered to have arrived with oyster shipments. These include three protozoans, one seaweed, five sponges, five hydroids, two anemones, four oligochaete and eight polychaete worms, an ostracod, a copepod, six amphipods, a crab, three opisthobranchs, six snails, two mussels, four clams, a kamptozoan, five bryozoans and five sea squirts (Cohen & Carlton 1995). One notorious example is the Asian ‘strangle weed’ *Sargassum muticum* (Sargassaceae), a brown macroalga from North-East Asia.

Sargassum muticum is a medium to large (2-10 m) yellow-brown, bushy seaweed native to Japan, East China and Korea, where it is found in lower intertidal and shallow subtidal waters of quiet bays and lagoons. It colonizes mud and sand flats and seagrass beds (*Zostera marina*), as well as fastening to solid substrates including oysters and rocks. *S. muticum* is fast growing and becomes fertile within one year of growth, and has been out-competing local seaweed species in both North America and Europe from the 1940s to present. It was initially introduced to North America via the shells of *Crassostrea gigas* or with oyster spat packing material and substrate transplanted to the Pacific coast, becoming established in British Columbia (Canada) before 1941. Detached branches, rendered buoyant by air vesicles, are dispersed by water currents and wind drift down the Pacific Coast. Fouled hulls of coastal shipping may have also carried the seaweed into ports such as Oakland in San Francisco Bay.

The spread of this weed along the Pacific coast of North America has been summarised by Jacono (1998). Although established in the Straits of Georgia (British Columbia) before 1941, the earliest US observation was made near Coos Bay (Oregon) in 1947. Subsequently found invading northern Willapa Bay (Washington) by 1953, then in more exposed areas at the San Juan Islands and Straits of Juan De Fuca, followed by northern California (Crescent City) in 1963. Reported ten years later in San Francisco Bay, attached to hard substrates in low intertidal areas, having already established further southward near San Diego (including the Monterey Bay National Marine Sanctuary and Santa Catalina Island). Currently a dominant intertidal species at the Channel Islands and in the Santa Barbara area, and well established in the waters off south-eastern Alaska and British Columbia.

Apart from its local abundance along many parts of the North American Pacific Coast, it has also been introduced to the coasts of Britain (including Northern Ireland), France, the Netherlands, Denmark (e.g. Limfjorden) and in the Mediterranean Sea, where it invades various rocky and sandy habitats including those occupied by the seagrass *Zostera marina*. (e.g. ICES 1999). These 'eelgrass' beds are important nurseries for many marine species. Their displacement by *S. muticum* is feared to disrupt coastal embayment ecosystems in both America and Europe.

Another oyster shipment hitch-hiker has been the green macroalga *Codium fragile tomentosoides*, known as the 'Oyster thief in Canada. This green alga is another native of East Asia and Japan but is also now common in Europe and many other locations. It was first detected in Canada 1996 at Caribou, Nova Scotia (Gulf of St Lawrence). Oyster thief smothers mussels and oysters, preventing them from opening their shells to filter feed. Starved and weakened shellfish are easy targets for predators. Gas bubbles trapped under dense mats of oyster thief can lift shellfish off their beds, and float away with them. Fouling caused by the alga results in increased labour costs in shellfish harvesting. Together with clubbed tunicates (*Styela clava*; another introduced species[13]), the oyster thief can weigh down floating docks, making them difficult to remove from the water. Oyster thief displaces native kelp, a preferred habitat used by many species, including sea urchins and lobster. (DFO Canada 2003). Because of the many inadvertent introductions experienced from the transfer of mariculture species, both ICES (1994) and DFO Canada (2002) have released new codes for these activities, with similar produced by other countries.

4.8.2 Successful Eradication of an Established Oyster Pest

This case history is summarised from GISP 2001, Bax *et al*. (2002) and Galil (2003). The original references are Culver CS & AM Kuris (1999, 2000). Shell-boring sabellid polychaetes, *Terebrasabella heterouncinata*, were discovered in California in 1993 in a mariculture facility, following its inadvertent translocation to California in a shipment of abalone seed stock from South Africa. This worm causes shell deformations and slowed growth in cultured abalone, and was initially contained in mariculture facilities. By 1996, however, a high prevalence of the sabellid worm on native black turban snails (*Tegula funebralis*) in the intertidal zone in the region of an outflow of a Californian abalone hatchery near Cayucos, indicated an alarming spread.

An eradication programme based on the epidemiological theory of 'threshold of transmission' was implemented in 1996, with the goal of reducing the density of both the transmissive stages and their highly susceptible hosts to levels below the replacement infection rate, thereby causing smaller successive generations that eventually die out. The approach required:

(1) installing screens at the mariculture plant to prevent further releases of adult worms and removing facility-related marine debris from the area;

(2) reducing the size of the adult pest population; and

[13] The clubbed tunicate (*Styela clava*) is a native from the western Pacific but has a wide cosmopolitan distribution via historic and contemporary hull fouling. It was recently reported in Canada at the Brudenell River mouth, Prince Edward Island (Gulf of St Lawrence) in January 1998. Clubbed tunicates grow in dense clumps of up to 1,000 individuals per square metre. Adult tunicates can reach a length of 16 to 18 cm. Infestation of docks, buoys, and other hard surfaces has occurred from the low tide mark to depths of 4 to 5 metres. Clubbed tunicates interfere with the settlement of oyster and mussel larvae, compete for space and food with young oysters and mussels and are considered serious pests of aquaculture.

(3) reducing the numbers of susceptible native hosts, which comprised removing all gastropods, hermit-crab shells and empty shells from 1500 m^2 of the intertidal zone near the facility (including 2000 escaped cultured abalone shells and approximately 1.6 million *T. funebralis* shells).

The eradication efforts included coating cultured abalone shells in waxy substances, immersing them in freshwater or in warm seawater close to the upper thermal tolerance limit of the abalone. Microencapsulated and water-soluble toxins were examined but not employed. Surveys of *T. funebralis* snails conducted for two years after the removal program confirmed the complete eradication of *T. heterouncinata* population, with infestation rates dropping from 32% to zero (Culver & Kuris 2000). Programme success stemmed from:

(1) the early detection of the wild population, fortuitously in locations amenable to control and management;

(2) co-operation between commercial interests, regulatory agencies, and pest control scientists;

(3) existing information and theoretical basis for the adopted control strategy;

(4) a rapid but coordinated response based on this scientifically developed strategy;

(5) a persistent field effort plus monitoring of eradication efficacy through use of sentinel habitat experiments.

4.8.3 Asian Rapa Whelk - *Rapana venosa*

The veined Rapa whelk *Rapana venosa* (syn. *R. thomasiana*) is a marine gastropod of the Muricidae family that became established in the Black Sea during the 1940s (first reported in Novorossisk Bay in 1946), and where it subsequently caused a precipitous decline of local mussel and oyster beds. Reproduction involves the production of sticky egg capsules that are deposited on hard subtidal surface and hatch after 12-17 days. The pelagic larvae remain in the water column for 14-17 days before settling. Introduction of *R.venosa* from its native Sea of Japan - Yellow Sea - East China Sea area is thought to have occurred via hull fouling of egg masses, although transport of its larvae in ship ballast water tanks has not been discounted (e.g. Zaitsev & Oztürk 2001, Kideys 2003). Its subsequent appearance in the northern Adriatic Sea during the 1970s has been considered a secondary ship-mediated dispersal from the Black Sea (Zolotarev 1996), so far without apparent severe consequences (Ochipinnti-Ambrogi 2003).

R. venosa has since entered the northern Aegean Sea (two specimens were reported in Thessaloniki Bay in 1991; http://www.ciesm.org/atlas/Rapanavenosa.html), and it has been introduced to Chesapeake Bay and Hampton Roads (Virginia) on the eastern seaboard of North America (as of October 2003 more than 5,600 records, including shells dating back to the first collection in August 1998; http://www.vims.edu/mollusc/research/merapven.htm). A substantial collection and research effort may have contributed to its apparent lack of expansion or spread between 1998 and 2002 (Figure 3).

While *R. venosa* has exterminated most native oyster (*Ostrea edulis*), scallop (*Pecten ponticus*) and mussel (*Mytilus galloprovincalis*) beds in the Black and Azov Seas, its burgeoning population spawned a substantial commercial fishery that exports its shelled meat mainly to Japan and Korea (e.g. Kideys 2003). *R. venosa* has experienced little, if any, predatory pressure in the Black Sea, with commercially significant harvests commencing in the late 1980s. Annual catches from Turkish waters were initially around 10,000 tonnes (shelled meat; 1988 and 1989) before stabilising to around 4,000 tonnes annually worth US$2.2 million dollars (by contrast the collapse of the anchovy and other Black Sea fisheries following the ballast water-mediated 1980s introduction of the voracious comb jellyfish *Mnemiopsis leidyi* caused several hundred million dollars economic damage to the Turkish sector alone). There are presently 11 factories along the Turkish Black Sea coast which process the *Rapana* shell meat for export (Kideys 2003).

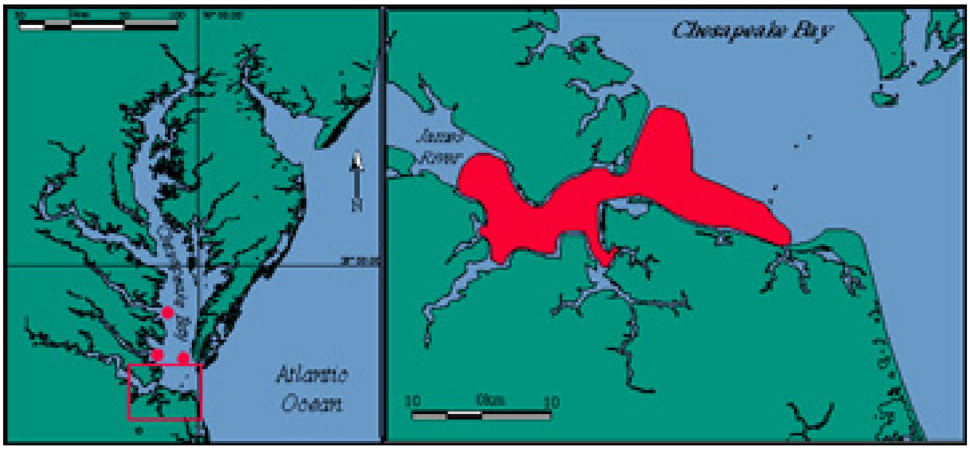


Figure 3: 1998-2002 range of *Rapa venosa* in the mouth of Chesapeake Bay
(from http://www.vims.edu/mollusc/research/rapaw/merapmap.htm ; 20 December 2003)

Apart from its wide acceptance in East Asia, *Rapa's* culinary appeal has received highly favourable reviews of recipes recently taste-tested in Virginia (Rapa Whelk with Linguini, Rapa Fritters and Rapa Chowder at a Norfolk (VA) restaurant with much publicity (http://www.vims.edu/mollusc/research/rapaw/rapup.htm). With Virginia's bounty program continuing to operate at US$5 per live specimen and US$2 per dead animal or shell, it is clear the case history of *Rapa venosa's* invasions and management responses is far from conclusion in both North America and Europe.

4.8.4 Edible Mussels and Oysters

As with zebra mussels in the Great Lakes, efficient suspension feeding by dense populations of *Perna* mussels may disrupt the phytoplankton assemblage and increase water clarity, with their faeces and pseudo-faeces diverting nutrient recycling pathways to the benthic community. Dense mussel populations also cause physical and competitive changes to benthic community dynamics, while their mass settlements can cause substantial nuisance fouling to vessel hulls, bridge pylons, navigational aids, mooring buoys and the cooling water systems of ships and coastal power stations.

4.8.4.1 New Zealand Greenlip Mussel- *Perna canaliculus*

The greenlip mussel *Perna canaliculus* (Bivalvia, Mytilidae) is native to New Zealand, grows to a large size (>120 mm) and forms a significant component of the shellfish culture industry, much of which is frozen and exported internationally. Settlement of greenlip mussel spat is common on hulls and piles where anti-fouling coatings are old, damaged or 'pre-conditioned' by biofilms, filamentous green algae and other pioneering foulers such as the balanid barnacles, bryozoans, hydroids and solitary ascidians (sea squirts).
In 1996, evidence of a small founder population of greenlip mussels was discovered in South Australia near Port Adelaide, in the Gulf of St Vincent. It comprised approximately two dozen mature mussels, all of a similar size, which were attached to a large razor clam that was

removed from the seafloor of a shipping channel by marine scientist SCUBA divers during a research dive. Subsequent sledge-dredge and diver surveys of the area, which is near the Outer Harbour wharf of the port, found one more individual. Follow-up surveys of the areas considered most likely to be colonised by a reproductive event (via local water currents) have found no more mussels (in Bax et al 2001). Removal of this species from the open waters of the Gulf of St Vincent represents a successful eradication that was made possible by the serendipitous discovery of a small founder population of an easily recognisable species. The specific route of the introduction has remained unclear. While hull fouling is suspected, ballast water or discarded fishing gear cannot be discounted.

4.8.4.2 Asian Green Mussel - *Perna viridis*

The following case history is one of the most detailed in this review, as it presents the type of information that needs to be collated from internet and hard copy sources when responding to the discovery of a new marine introduction (in this case from Benson *et al*. 2001, Crochet *et al*. 2000, NIMPIS and US). The Asian green mussel *Perna viridis* (Bivalvia, Mytilidae) is a large, popular edible shellfish which represents the tropical Indo-Pacific counterpart of temperate blue mussels such as *Mytilus edulis* (Crochet *et al*. 2000). It is highly sought after throughout much of its present Indo-Pacific range, where it colonises coastal, estuary and tidal creek shores and shallow hard substrates. Natural and farmed *P. viridis* are taken in India, Malaysia, Indonesia, the Philippines, southern China (including Hong Kong) and French Polynesia (e.g. Jones & Alagarswami 1973, Choo 1974, Kuriakose & Nair 1976, Sivalingam 1977, Phillips 1980, Siddall 1980, Coeroli *et a*l. 1984, Morton 1987, Rajagopal *et al*. 1998).

It is a popular culture species because reproduction can be induced throughout the year and it can be easily transplanted with minimal losses (Sivalingam 1977, Parulekar *et al*. 1982, Coeroli *et al*. 1984). It has undergone substantial human-mediated range extensions during the 19th and 20th centuries via hull fouling and deliberate transfers for both subsistence and artesanal commercial use, with its present day 'native' distribution typically reported to extend from the Middle East (where there is confusion regarding the presence and possible synonymy with so-called painted mussels, *Perna picta* and *P. indicata*) to southern Japan and islands in Micronesia and Melanesia, including Papua New Guinea.

Figure 4: Asian Green Mussel – *Perna viridis*

Spawning is reported to be induced by the presence of other spawning individuals in the area and a drop in salinity following the start of tropical monsoon seasons (Stephen & Shetty 1981). In South Asia spawning occurs in both monsoon seasons (March-April and October-November; Slivingham 1971, Stephen & Shetty 1981) but in humid equatorial regions it can breed almost continuously throughout the year (e.g. Johore Straits, Singapore and Quezon, Philippines; Tham *et al*. 1973, Choo 1974, Walter 1982).

Mobile trocophore larvae are produced within eight hours of fertilization, with the veliger larval stage developed within 24 hours and metamorphose to adults after 8-10 days, settling and and secreting their initial byssal threads in 10-12 days (Tan 1975, Siddall 1980). Newly settled spat grow fast with maximum growth rates 2 m below the surface because of reduced fluctuations in food supply, temperature and salinity (Sivalingam 1977, Rajagopal *et al.* 1997). *Perna viridis* has a wide salinity tolerance (10-80 psu) and high survival rates in both turbid waters and intertidal sites with long exposure times (Sivalingam 1977, Morton, 1987). It may be vulnerable to an apparently rare and unidentified *Gorgoderina* digenetic trematode parasite which has been found in adults (Koya & Mohandas 1982).

Because of its popularity and high removal rates by subsistence, artesanal and commercial fishers, its potential invasive and nuisance impacts in the Indo-Pacific have remained unclear. While it is considered beneficial in most of the tropical Indo-Pacific region, its discovery in Trinidad in 1991 and subsequent spread to ports in Venezuela (1993), Jamaica (Kingston) and Florida (from Tampa to Charlotte Bay; 1999-2000) raised considerable concern as to its ability to spread and disrupt native benthic communities in the Caribbean region, particularly if populations establish in mangrove areas via self-mediated dispersal, larvae entrained in ballast water and/or hull fouling (CRP).

The species is now well established in Florida, being first discovered in 1999 by divers undertaking maintenance work in Tampa Bay at the TECO powerplant in South Hillsborough County (Tampa Bay Estuary Program 2000). Asian green mussel fouling has caused problems to coastal power plants by clogging pipework and reducing heat transfer efficiencies (Rajagopal et al. 1994, 1996). Constant low levels of chlorination do not kill all adults, with high-level chlorine pulses required to kill and detach them from seawater intake tunnels (Rajagopal *et al*. 1996). They can also increase corrosion rates of fouled surfaces, and they have been notorious for fouling navigation buoys in the South China Sea where biomasses have reached 72 kg/m^2. Other potential negative impacts include competition with any mariculture industry (including pearling and oyster culture), as well as potential displacement of native rocky shore benthic assemblages and alteration of nutrient pathways.

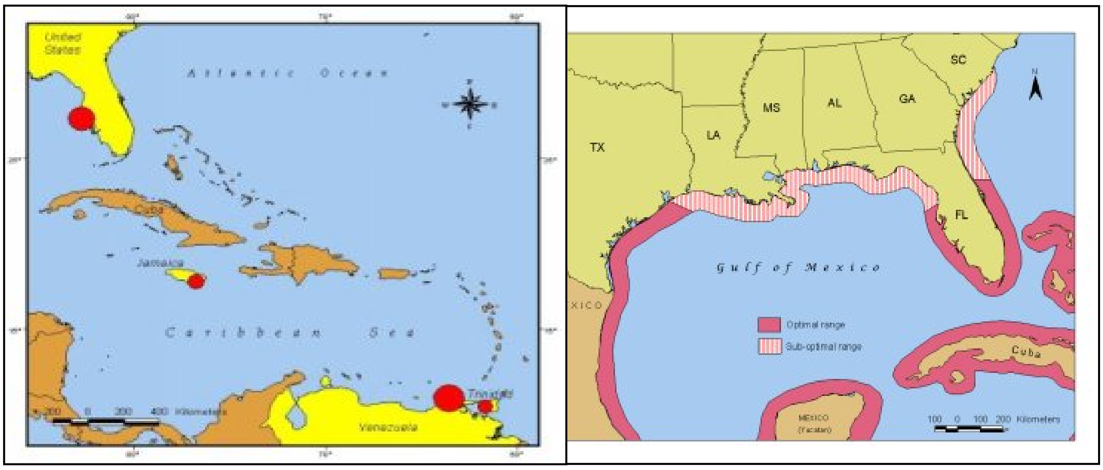


Figure 5: Recent (2001) and predicted potential range of *Perna viridis* in the Caribbean and Gulf of Mexico region (from Benson *et al*, 2001).

Follow-up monitoring in Tampa showed the mussels first colonized mostly artificial habitats such as bridges, docks, channel markers and buoys, and survives in areas where winter water temperatures declined to as low as 12°C (native range water temperatures are typically above 16°C). Benson et al (2001) consider the maximum lower limit of *P. viridis*' sub-optimal range is possibly as low as 10°C (as based on LT_{50} results for two weeks exposures).

Until 2001, records of *P. viridis* in Australian waters were limited to the occasional specimens found during hull surveys of fishing vessels visiting northern ports such as Darwin (Section 4.3). On 11 August 2001, dense clusters of this mussel were discovered in the Port of Cairns

(Queensland) on the foreign fishing vessel MV *Wing Sang 108*, which had been slipped for a hull cleaning operation (Section 4.7) From the mussel clusters removed from the cooling water intakes (>25/m^2), five were sent to the Curator of Molluscs at the Northern Territory Museum and confirmed as *Perna viridis*. It was concluded that the origin of these mussels was from spat settlement during its previous lay-up/s in one or more Indonesian harbours.

Because *P. viridis* had been listed as one of Australia's unwanted 'next pests', and the *Wing Sang* had been moored inside the Port of Cairns for over 1 year since its seizure by Australian Customs (Section 4.7), its hull cavities were sealed and QEPA notified the national Australian *Coordinating Committee on Introduced Marine Pest Emergencies* (CCIMPE) to assist in developing a rapid response. The initial response comprised a low tide visual inspection survey of 18 shoreline sites in and near the tidal and estuarine creeks of the Trinity Inlet mooring areas. No mussels were detected and, after a further inspection of the *Wing Sang 108*, the vessel was subsequently disposed of at a deepwater site in December 2001.

The same agencies involved in the evaluation of the Caribbean tubeworm *H. sanctaecrucis* were involved in this response (Section 4.7), with the inclusion of the Queensland Departments of Primary Industries and Transport. An education/awareness brochure outlining the risks of transferring *P. viridis* and other unwanted species by hull fouling, and outlining the actions to reduce this risk, was published and distributed in July 2001. In November 2001 one juvenile mussel was found during the Cairns Port baseline survey for introduced marine pests, as conducted by CRC on behalf of the Cairns Port Authority (CPA). Within a fortnight all port stakeholders were notified and additional delimitation surveys undertaken by CRC, and further juveniles were found. These were removed and a follow-up inspection survey was made. All stakeholders were subsequently invited to a workshop convened by CRC Reef on the Asian green mussel in February 2002.

A number of action plans were drafted by QEPA for consideration by CCIMPE. at the workshop. This led to a Quarantine area established in Trinity Inlet on 19 March 2002. During the 3 month quarantine period, movement of vessels was halted, and 134 vessels were inspected either by divers or on slipway, with fouled, high risk vessels slipped/cleaned and the internal piping systems of all quarantined vessels treated without charge owners. A total of 16 mussels were found during the quarantine exercise. In April 2002 QEPA formally briefed all Queensland port authorities as to the potential continuing presence of solitary and widely dispersed adults on vessels and other artificial substrates at Cairns. CCIMPE conducted a training workshop in Darwin in June 2002, to which stakeholder representatives from Cairns attended. Over the remainder of 2002, 22 more mussels were found on the hulls of a number of different vessels.

In January 2003 the QEPA hosted another workshop to discuss findings to date and future actions, including requirements for 'Proof of Freedom'. One the 26 September 2003, a motor vessel which had been moored at Cairns for two years was moved out of Cairns and eventually slipped one month later at Flying Fish Point (a small boat harbour to the south of Cairns near Innisfail. inside the ports limits of the Port of Mourilyan). A single but large (142 mm) adult green mussel was discovered on the hull by the slipway operator, who had previously seen the QEPA brochure.

The discovery led the Port Authority for Mourilyan (Ports Corporation of Queensland) to deploy four settlement monitoring devices which were modified for encouraging settlement of *P. viridis* (Figure 6). The modifications comprised additional PVC pipes (30 cm x 5 cm) fixed horizontally. No further adults or spat have been detected at either Cairns, Innisfail or Mourilyan. Communications continue on a periodic basis between all parties, including public and stakeholders. *P. viridis* is still presumed to be present in very low densities, based on the results to date (i.e. less than 100 mussels detected in total). Awareness of the risk of introduced taxa, has been maintained within the local industry, public and government sectors. QEPA's 'Proof of freedom' action plan is being implemented for monitoring Trinity Inlet over the next two years to confirm if it is free of the mussel. Estimated costs for the mounting the various response actions to date have amounted to over AUD$250,000 (approximately US$200,000).

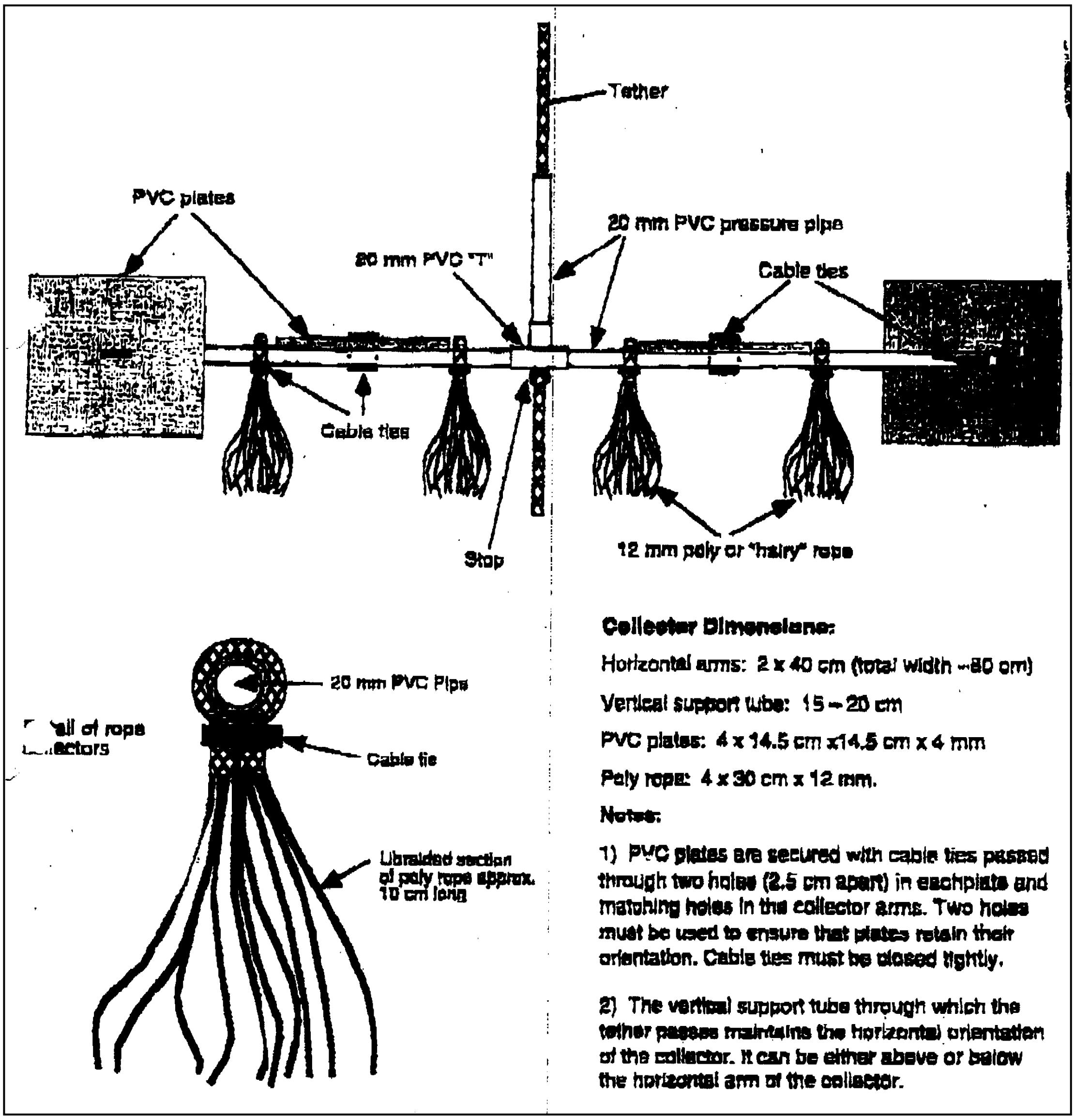


Figure 6: Details of the Settlement Monitoring Device deployed in Queensland ports and harbours to detect introduced mussels and other taxa
(from S. Trimarchi; Ports Corporation of Queensland, Brisbane)

4.8.4.3 Blue Mussels (*Mytilus spp.*)

Of the four species forming the blue mussel complex (*Mytilus edulis, M. galloprovincalis, M. trossulus* and *M. californianus*), all have been involved in deliberate translocations for mariculture purposes, with the north Europe *M. edulis*) and south Europe *M. galloprovincalis* being the most successful in colonising regions beyond their native range (i.e. Canada and South America, and Australia, California, New Zealand and South Africa, respectively).

It is interesting that the economic and social value of *M. galloprovincalis* to mariculture operations in South Africa and southern Australia have outweighed concerns as to its ability to spread and alter native communities, particularly its displacement of native mussels along South African coasts where substantial changes to rocky shoreline communities continue to occur. *M. galloprovincalis* is so far not listed an harmful or pest species in either country. The origins, genetic makeup and introduction pathways of the blue mussel complex have raised much interest, particularly following realisation that three of the four species are present and/or cultured on the Pacific coast of North America (e.g. Gosling 1992, Seed 1992).

4.9 EUROPEAN GREEN CRAB - *CARCINUS MAENAS*

This crab has invaded both the Atlantic and Pacific coasts of the USA, eastern Canada, parts of southern Australia, South Africa and Japan (Tokyo Bay) via several vectors, including solid ballast exchange, hull fouling and inadvertent introductions with mariculture species. Green crabs are voracious predators eating a variety of species, especially shellfish such as clams and mussels. Green crabs are smaller and more aggressive than native rock crabs in North America and Australasia, and some of their populations have been reported to spread more than 100 km in some years.

It was introduced to the eastern seaboard of the USA some 200 years ago, and has since spread and damaged fisheries, aquaculture and native shoreline crab faunas. It greatly diminished the numbers of the commercially valuable soft-shell clam *Mya arenaria* in Maine during the 1950s, and has continued to spread to New England and Canada. It was first observed in St. Georges Bay, Nova Scotia (southern Gulf of St Lawrence) in 1995. Green crabs also affect Canadian eel fisheries (eels will not enter traps if it contains green crabs; FAO Canada: Aquatic Invaders in southern Gulf of St. Lawrence: Appendix A).

The European green crab was first found on the west coast of the US in 1989-90 near Redwood City in the San Francisco Bay-Delta region, which is one of the most invaded aquatic ecosystem in North America (over 200 non-native aquatic species recorded). It has since moved steadily northward at a rapid rate. In 1998, researchers on the north-west Pacific seaboard of the US invited Andrew Cohen from the San Francisco Estuary Institute to survey a stand of non-native cord grass invading Willapa Bay, in south-western Washington. Within 30 minutes he came across and recognised a moulted shell of a male European green crab; evidence that the species had reached Washington. While there had been an enormous amount of publicity about its predicted arrival in Washington State, with many local people alerted and encouraged to keep an eye for green crabs, it was a researcher familiar with the particular species who discovered the first evidence of its arrival (http://www.sfei.org/invasions.html; Appendix A).

It is considered to be a serious threat to the fisheries and mariculture industry of the Pacific Northwest (with an estimated value of US$45 million/year) and wildlife. Native birds and Dungeness crabs have been singled out as particularly at risk, from predation and/or competition. Substantial declines in other crab and bivalve species have been measured in California and Tasmania, Australia. Native shore crab population declines are greater than 90% in some areas. In its home range the green crab is found in protected rocky, sandy and tidal habitats, and this has so far been the case in ?South Africa and Australia, where it has yet to gain a substantial foothold on exposed, wave-swept rocky shores and surf beaches.

Physical removal of *C. maenas* by divers might provide a solution in small, enclosed areas such as mariculture facilities, but this approach is ineffectual over large areas. Exclusion barriers such as low wire fences used by the New England clam fishery, trapping and poisoning with Lindane or Carbaryl-soaked bait have proved unsatisfactory (in Galil 2003). Compared to native populations in Europe, those from all invaded areas have experienced a release from their natural enemies, and reach larger sizes and loose fewer limbs than their native European counterparts.

The introduced populations have also escaped European parasites that have direct effects on their reproduction, such as the rhizocephalan parasitic barnacle, *Sacculina carcini*, which infests *C. maenas* throughout its native range. However this natural parasite, which blocks moulting of its host and causes castration, has also been found to similarly infect native Australian crabs, and therefore is not readily suitable as a biological control agent (Thresher 2000). While this barnacle parasite also causes female sterility in *C. maenas*, genetic work has also shown that *S. carcini* taken from several portunid crab genera in Europe cannot be distinguished genetically, highlighting the problem of host specificity. Other potential bio-control agents include viruses, dinoflagellates, ciliates, the egg-predator nemertean *Carcinonemertes carcinophila*, nematodes, tapeworms and an epicaridean isopod (Goggin 1997, Kuris 1997, Galil 2003).

4.10 PROVIDENTIAL BIOCONTROL OF THE ATLANTIC COMB JELLY

The Atlantic comb jelly *Mnemiopsis leidyi* helped to radically alter the community structure, nutrient cycling pathways and pelagic-benthic ecology of the Black Sea between its ballast-water mediated introduction in the early 1980’s and the height of its impacts in the mid-1990s. The Group of Experts on the Scientific Aspects of Marine Environment Protection (GESAMP) convened to discuss possible strategies for the control of *M. leidyi* and concluded eradication was unlikely since the area affected was far too large for any practicable solution (GESAMP 1997). Mechanical removal or destruction was deemed impractical because of its high growth rate, while toxic chemicals at the concentrations required to exterminate *M. leidyi* would damage the whole food web. Biological control strategies were therefore identified as offering the only feasible approach for reducing its abundance, via selection and use of some pathogen, parasite, predator or competitor.

Species of the comb jelly genus *Beroe* were considered as biocontrol agents as they feed exclusively on *M. leidyi* and other ctenophores, and have equally high reproductive rates. Providentially, *Beroe ovata* appeared by itself in the Black Sea in 1997 (Zaitsev 1998), and its subsequent rapid increase in its abundance was concomitant with significant reduction in *M. leidyi* biomass and increase in zooplankton and fish egg biomass between 1999 and present. In fact it is doubly fortunate that *B. ovata* not only undertook the same ship-mediated vector and route of introduction as *M. leidyi* but has also shown no preference for the local native zooplankton.

M. leidyi was recorded in the Caspian Sea for the first time in November 1999, an unsurprising result given that several species have moved into the Caspian via ship-mediated range extensions following the opening of the Dom-Volga ship canal (Section 4.3). This invader has undergone a similar population explosion , possibly in response to the abundance of zooplankton owing to previous over fishing, eutrophication and pollution pressures in the Caspian. It has therefore been suggested if *B. ovata* does not repeat the same transfer, it should be deliberately introduced to provide a similar control *M. leidyi* in the Caspian Sea, and thus improve the chances of fishery stock recovery programmes. It is necessary, however, it carefully examine the native zooplankton fauna of the Caspian and evaluate the risk, since the two inland seas are different in many respects.

4.11 ASIAN GOLDEN MUSSEL - *LIMNOPERNA FORTUNEI*

The Asian golden mussel (*Limnoperna fortunei;* Mytilidae) is a relatively small mollusc native to the river systems of China. It is sufficiently euryhaline to tolerate the low salinity regimes in river mouths and upper estuary areas. This mussel has become a serious nuisance fouler in Brazil, Argentina and Uruguay (including the Yacyreta and Itaipu hydroelectric power stations), has no predators, and is altering the benthic ecology of these river systems.

It was first discovered in South America in 1991 on the Argentine side of the large La Plata (Plate) River at Bagliardi. By 2000 it had spread a long way upstream (1100 km) via hull fouling and possibly waterfowl into the upper reaches of the Parana River (Brazil and Paraguay), including the city of Corumba in the Pantanal region. High densities continue to occur at many locations throughout its new range, including Porto Alegre on the Guaiba River, Arambare in Brazil and Bagliardi in Argentina.

Because of the trading waterway connections between the Parana – Tocantis – Amazon rivers, there are great fears this thermally tolerant mussel is capable of penetrating the Amazon Basin. International workshops have been held and several research efforts are currently underway to improve knowledge of its lifecycle biology, the main pathways of spread and potential biological control agents (F. Fernandes 2003, unpubl, pers comm.).

4.12 CHOLERA (*VIBRIO)*, OTHER PATHOGENS AND TOXIC ORGANISMS

As described by Ruiz *et al*. (2000), a wide range of human and fish disease organisms can survive in ballast and bilge water and generate remarkably high concentrations, and there is evidence that cholera bacteria (*Vibrio cholerae*) can increase in number more successfully within ballast tanks than outside in normal estuarine and marine waters (Manning *et al* 1994, McCarthy *et al* 1994). Bacteria and viruses that can directly infect humans through direct contact with fresh, brackish and marine waters (and ingestion of infected seafood) include gut pathogens associated with faecal particles (coliform gut bacteria *Escherichia coli*), cholera bacteria (*Vibrio cholerae*), botulism (*Clostridium* spp.) and various viruses such as Type A hepatitis.

As a general rule of thumb, the higher the concentration of faecal and other organic material that may be suspended in the water column of ballast water uptake areas, the higher the chance that human disease agents will be uptaken and survive the voyage. This was recently demonstrated for the suspected ballast-water mediated transfer of cholera bacteria from Venezuela to Mobile, Alabama (although these bacteria were also present in the bilges and sewage water of arriving vessels that were subsequently tested; McCarthy *et al* 1994).

The trans-Caribbean transfers were discovered following the detection of the Latin American cholera strain on two occasions in 1991, from routine sampling of closed oyster beds near Mobile, Alabama. The salinities of the ballast water of the five vessels ranged from 12 to 32 parts per thousand (McCarthy & Khambaty 1994). Previous incidents involving possible but unconfirmed shipping-mediated transfers of cholera include five cases in 1991. These were caused by the consumption of infected raw oysters taken from Apalachicola Bay in Florida (Wilson *et al*, in McCann 1996).

Australian evidence for potential botulism transfers by ballast waters indicates a low incidence (e.g. 1 in 281 ballast water samples tested by the CSIRO Food Processing Division). The one positive sample that was obtained came from ballast water sediments from a ship that had returned to Queensland after visiting Singapore (Gibson & Eyles, cited in

Hilliard *et al* 1997). Other tests have shown that *Clostridium* strains can survive in marine sediments at various temperatures between 5°C and 20°C for 28 days.

Other single-celled organisms hazardous to human health and transferable by the ballast water vector include the toxic strains of dinoflagellates, which can form tough, benthic resting stage cysts and be sucked into ballast tanks with port sediments. Apart from well known red tide species such as *Alexandrium*, *Pfiesteria piscicida* and *Pfiesteria-like* organisms began causing widespread concern in the Chesapeake Bay region and the Atlantic seaboard due their association with fish kills, ulcerative lesions on fish and human health disorders.

Large fish kills occurred in the Pocomoke River, Maryland in 1997, and neurocognitive disorders and skin irritations were reported by local watermen and others who use the Pocomoke River. In laboratory studies at North Carolina State University, exposure to *Pfiesteria* culture water was cited as the cause of neurocognitive disorders experienced by two researchers. A documentary produced by Maryland Sea Grant, *The Pfiesteria Files*, shows how researchers and environmentalists in Maryland and North Carolina responded to its appearance.

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5. LITERATURE REVIEW - BEST PRACTICE MANAGEMENT

5.1 RESPONSES TO MARINE BIOINVASIONS - OVERVIEW

5.1.1 Information, Coordination and Legislation

The rapid rise in the number of reported marine introductions and harmful invasions over the past twenty years has caused a substantial expansion in aquatic bioinvasion research and management effort. Despite this expansion, major gaps began appearing in the 1990s between the need for useful policy information 'to act/manage now' and the conventional process of collating and distributing reliable knowledge via fund requests, research and review. Another issue was the need to maintain an adequate level of international coordination, cooperation and collaboration required for the effective management of the shipping vectors.

In response, many organisations, government agencies and international 'umbrella' groups took advantage of the world-wide-web to launch a range of Internet-based information systems. Various formal and informal e-mail-linked working groups were also established to help:

(a) improve the ability of researchers and managers to keep pace with the proliferation of informal and formal communications containing knowledge and policy advances,

(b) reduce the incidence of uncoordinated research and unnecessary duplication of effort,

(c) promote multi-lateral understanding and unified decision-taking, both between nations and between provinces and states within nations,

(d) provide materials for education, community and industry support, out-sourcing and awareness-raising, and

(e) commence work for integrating regional databases on aquatic NIS distributions.

Examples are the various regional, national and international clearing houses and directories of research and policy efforts (in Appendix A), which also have links to other information sources and databases. They include the directories on the IMO's GloBallast Program website in the UK, the *Aquatic Invasions Research Directory* (AIRD) on the US Smithsonian Environmental Research Center's (SERC) website, and the information sources placed on a variety of national, regional, government agency, NGO and industry websites (Appendix A). Some of these are now providing reports and publications on best practise management strategies, and more specific codes of practise for reducing the incidence and spread of marine incursions (Section 5.4; Appendix A).

Several developed countries began implementing new policies, legislation and regulations to strengthen their research and management responses to marine NIS during the 1990s. Several are now addressing policy inefficiencies and loopholes which have already emerged. In the case of Australia, it is now recognised from trials of its ballast water 'Decision Support System' that this system is less helpful for ballast water management on ships arriving from overseas ports compared to ships on domestic voyages, and that insufficient management attention was being paid to the hull fouling vector of both recreational and commercial vessels. In the case of New Zealand, it was recognised by 2002 that its marine border control system, as implemented by the *Biosecurity Act* 1993, was under-resourced and not effective (Box 4), with its weaknesses attributed to:

- lack of explicit inter-agency arrangements for comprehensive border management,
- significant lack of management tools for managing key pathways,

- insufficient post-border surveillance and monitoring, and
- lack of capacity which forced a patchy and essentially 'triage' approach in responses to incursions.

In the case of the United States, its lead agency for shipping and ballast water management (the Coast Guard) continues to remain involved in modifications to Federal legislative mechanisms, while some States and regional entities moved ahead of Congress to implement their own policies and requirements for ballast water management (e.g. California, Washington; Section 5.4). Because unilateral responses tend not to be uniform, they have raised concerns in the shipping industry (Section 5.4).

5.1.2 Past and Present Issues

5.1.2.1 Lessons from Responses to Terrestrial Bioinvasions

Dahlsten & Garcia (1989) reviewed eleven cases of terrestrial eradication attempts which had variable durations (1 to >40 years) and success, and their conclusions can be summarised as follows:

- 'Crisis management' comes from lack of preparedness and information for known and potential pests
- Crisis management may cause over-reliance or over-application of harmful chemicals;
- Funding may shift toward administrative rather than field components – particularly in big projects
- Insufficient attention was paid to identifying and evaluating the side effects of the eradication method;
- Scientific advice was sought only when the lead agency needed support, causing a lack of alternate viewpoints.
- Information provided to the public may represent the lead agency's singular view only.
- Insufficient monitoring and objective evaluation of the methods was used, providing little opportunity to improve or terminate inappropriate methods.
- Insufficient monitoring and lack of rational criteria for reviewing program progress and success.

Some of the case studies in Section 4 (e.g. the 'death weed' strain of *Caulerpa taxifolia* off Spain in the 1990s; Section 4.1), plus those in Section 5.1.2.3, provide comparable examples of unsuccessful attempts in the marine realm.

5.1.2.2 Is Prevention better than Cure…? The Need for Surveillance

All pest reduction and management strategies recognise the medical maxim: "*an ounce of prevention is worth a pound of cure*". Since prevention offers the most cost-effective line of defence, the 1990s saw considerable emphasis placed on the critical need to establish prevention-based strategies involving pre-border and border controls plus more effective quarantine mechanisms to reduce marine NIS incursions. Arguments for this strategy were underlined by the problems confronting managers when asked to respond to an established marine NIS incursion, especially:

- The lack of technologies which can apply affordable and targeted containment, eradication or control measures in open coastal waters.
- The limited availability of biological controls for marine species (via pathogens, parasites, predators or genetic or epidemiological manipulation), which is in its infancy compared to terrestrial pest management.
- The fact that most sessile and many mobile marine taxa have propagule and larval dispersal stages capable of substantial spread via local and regional water currents.
- The fact that many estuarine and brackish water taxa have wide thermal/salinity tolerances and are pre-adapted to take advantage of rapid changes in local conditions.

However, such arguments ignore a number of issues, some currently intractable, which will continue to constrain reliable prevention strategies for at least the short- to mid-term:

- Tthe operational nature of the international shipping industry, including the present overriding economic imperative placed on the need not to disrupt the movements and needs of trading vessels.
- The fact that most maritime nations lack convenient borders or political boundaries for establishing effective or affordable control measures, unless all their neighbours do likewise.
- The large number and range of different marine organisms which can be translocated by ballast water and hull fouling.
- The considerable knowledge gaps in marine taxonomy, life-cycle biology and contemporary native and introduced range distributions (even for some well-known marine pests).
- The problem in predicting which species threaten invasive and harmful consequences and which do not.
- The present and near-future unavailability of safe, practical and cost-effective methods for treating ballast water (including the time required to establish workable ballast water standards and treatment testing/verification methods for IMO's new convention; see Box 8 in Section 5.3).
- The difficulties in managing hull-fouling without recourse to overly toxic additives, such as the recently banned use of organotins (TBT) for anti-fouling coatings.

For these reasons there has been growing recognition that no current prevention system can provide a satisfactory level of border control and interceptions, and management systems which are overly focussed on the prevention approach will fail (Box 4).

The presence of NIS already present within the borders of many countries provides another reason why post-border management systems are required for detecting and controlling their populations to help reduce further port and watershed 'hopping' invasions via secondary and primary pathways. Current evidence also indicates that some aquatic species which initially may appear innocuous can eventually develop invasive and harmful traits in response to changing environmental conditions or through natural selection/acclimation processes[14].

[14] Cases where marine taxa have become nuisance species decades after their initial introduction include the Asian mitten crab, *Eriocheir sinensis*, in northwest Europe (re-emerged as a nuisance species 75 years after its first

BOX 4: Improving New Zealand's Biosecurity Management Strategy

New Zealand's *Biosecurity Act*, passed in 1993, was a world first - a law for the specific and systematic protection of all valued biological systems from the harmful effects of non-native pests and diseases. The act required several agencies to implement its statutes and achieve the required changes in systems and attitud, including the Ministries of Agriculture and Forestry (MAF), Fisheries (MFish), Conservation and Health. However, limited application of resources plus a concomitant rise in border control needs and incursion issues constrained their ability to mount a coordinated, effective approach. An independent review in 2002 confirmed that the country's biosecurity system was not adequately addressing border pressures, and was unable to reach balanced decisions for the greatest good.

Therefore a new Biosecurity Strategy was established in 2003 through a national review process. The new strategy focuses on pre-border, border and post-border activities and actions to keep out pests and to detect and respond to their incursions more effectively. The strategy requires all agencies, industry and individuals to take collective actions against pests. It does not focus on managing intentional introductions of new species or GMOs for culturing / farming activities (these are covered under a separate process). The strategy redistributes attention and effort from solely border control (prevention) to include surveillance and response components. The new strategy recognises that a rapid response capacity is needed, and that this requires:

- a surveillance system enabling detection of border incursions as early as practicable.
- a capacity to respond to detections (requiring funds and local/national logistical support);
- an ability to quarantine infested area/s as and where necessary.
- tools to eradicate, contain or control identified populations.
- a supportive legal framework.

5.1.2.3 Eradication attempts and lost opportunities

The following text is based on information in the APEC review by Williamson *et al* (2002), plus outcomes from Section 4 case studies and other sources (Appendix A).

Examples of determined but ultimately unsuccessful eradication attempts include the Atlantic gastropod mollusc (*Urosalpinx cinerea*) in eastern England in the 1950s, and the Japanese strangle weed (*Sargassum muticum*) in southern England in the 1970s (Hancock 1959; Critchley et al. 1986).

The 1950s English attempt to eradicate the nuisance gastropod *U. cinerea* involved a large-scale removal and destruction program conducted in Essex rivers, using a variety of physical and chemical control methods. These included dredging, trapping, instalment of chemical barriers and chemical dipping, the latter by immersing *Urosalpinx* and their host oysters in various solutions such as freshwater, formalin, potassium permanganate, chlorol (10% chlorine), phenol (0.15% in seawater) and copper sulphate (Hancock 1959; Spencer 1992, cited in Williamson *et al.* 2002).

The failure to control the Asian strangle weed *S. muticum* after its 1971 discovery in southern England has been documented by Critchley *et al*. (1986; cited in Williamson *et al*. 2002) and reviewed by Eno & Hamer (2002). This attempt also used a range of methods including

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 & Soulé 1999, cited in Williamson *et al* 2002).

handpicking, mechanical harvesting, herbicides and trials with native grazing molluscs. Hand-picking and shore-based mechanical harvesting were time-consuming, labour-intensive and their efficacy proved low and required many repeats. The incursion sites were difficult to access, the shoreline was damaged by equipment, and collected material was difficult to manage and dispose. Specially developed trawling and cutting equipment were not species-specific and caused considerable ecological damage. Efforts were ceased except for some mechanical cutting of weed to prevent choking of inlets, and some physical removal measures were reintroduced in the late 1990s in Northern Ireland to limit its spread in the Stanford Lough marine nature reserve (Eno & Hamer 2002)

While the risk of a failure may be high, this should not necessarily be an excuse to decide against an eradication attempt. The damaging invasion of sea lampreys in the Great Lakes invoked many electric barrier attempts until the eventual discovery of the larvicide TFM (Section 3.4.1). Application of TFM for sea lamprey and ruffe control in the rivers and streams of the Great Lakes region has been one of very few specific chemical treatments used in an aquatic pest eradication attempt (Busiahn 1996, cited in Williamson *et al* 2002). Because TFM was equally toxic to the larvae of native lampreys its usage and delivery regime were constrained. While its use could not eradicate the sea lamprey, TFM proved effective in controlling its density and spread, together with use of 'low-head' dams (J. Youson, Guelph, pers comm.). Improved electrical barrier designs have also been achieved (Section 5.2.8).

Evaluating the ultimate success and value of a long-term eradication or control campaign may not be straightforward. A program to eradicate a significant agricultural pest in Florida (the white fringed beetle *Graphognathus* sp.) was mounted soon after its discovery in 1936. The aim was to eradicate or at least quarantine this pest to its introduced locale. This 'quarantine' operation was officially terminated almost 40 year later (1975) when the beetle had spread to almost its entire ecological limits (Pitcairn & Manweiler 1989; cited in Williamson *et al.* 2002). This long term program might therefore be argued a success because the spread of the beetle was significantly slowed and delayed - buying time and maintaining agricultural profitability; a failure because the pest eventually spread throughout its ecological range; or a failure compounded by high environmental costs due to the program's broadcast use of chlorinated hydrocarbons (i.e. DDT and dieldrin).

Whether successful or not, there is no doubt that mounting an eradication or control program greatly increases public awareness as to the presence of marine pest species, and helps drive home the value and importance of the measures that the community and stakeholders can take to reduce the chance of future incursions.

Inaction during the appearance and early spread stage of *Caulerpa taxifolia* off Monaco is probably the most infamous example of a lost eradication opportunity (there would have been a high chance of eliminating this weed if a campaign had been mounted during the first five years of its presence; Section 4.1). Lack of strategic cooperation and forward thinking prevented this opportunity.

Another type of lost opportunity was the North Pacific seastar (*Asterias amurensis*) in the Derwent River (Hobart), which was incorrectly identified as a native seastar (*Uniophora granifera*) in 1987. The mistake was not realised until 1992. By this time the pest was so abundant that the chance of its possible eradication had been lost. By contrast, within two days of its discovery at Darwin in 1999, all relevant authorities had been informed that the suspicious black-striped mussel had been provisionally identified as *Mytilopsis* sp. - the invasive and unwanted marine 'cousin' of the dreaded zebra mussel from the same dreissenid family (Sections 4.2, 4.3).

A pre-existing strategic plan for responding to incursions of pre-identified pests can help guard against a lack of action when eradication could be achieved, as well as reducing the risk of mounting inefficient, ineffective or unwarranted eradication attempts. The lack of such planning was identified as one of the major difficulties with the initial attempts on the eradication of the *Caulerpa taxifolia* incursion near San Diego (where initially there was no clear line of authority, no clear funding and a lack of appropriate permits; B. Hoffman, cited in CSIRO 2001). Similar conclusions were reached in Australia during a national 'lessons-learned' review of the black-stripe mussel eradication campaign at Darwin.

5.2 BEST PRACTISE MANAGEMENT STRATEGIES FOR MARINE SPECIES INVASIONS

5.2.1 Separation of Mariculture – Vessel Management Mechanisms

Because of the historic importance of aquaculture both as an industry and a well known source of unwanted parasite and pathogen introductions, many countries continue to divide marine NIS management into two spheres which may not be administered by the same agency. These are:

(1) Management of NIS introductions via the Aquaculture and Aquarium Trade

This is often administered by a fisheries ministry, often in collaboration with quarantine, environment protection and/or nature conservation agencies. This area of management is now facing the need to become involved in decision-taking regarding the import and use of aquatic GMOs and transgenic forms developed for the aquaculture and aquarium trade.

Perhaps the best known code of management for intentional introductions has been the ICES 1994 '*Code of Practice on the Introductions and Transfers of Marine Organisms*'. Many countries reviewed or updated their codes of regulations and guidelines following release of this ICES document. The ICES code describes the assessment and quarantine measures that should be followed to:

(a) avoid intentionally introduced species that have undesirable characteristics, including any known or suspected potential invasive, noxious or other pest attributes, and
(b) minimize the unintentional introduction, release or escape of unwanted pathogens, parasites, commensals or other 'hitch-hiker' species via the shipment or handling of cultured species or through other mariculture vectors.

By 2000 it was clear that issues arising from the use of transgenic stocks and the proliferation of marine ranching operations (Section 3.3.3) were overtaking the ICES code. A number of recent reviews and position papers advancing the need for tighter practises in mariculture management have been published (Appendix A). Calls have included a complete prohibition on the use of non-native species and genetically modified strains in any farming system in which the potential for escape is greater than near zero (Weber 2003).

(2) Management of Unintentional Introductions via Pathways Unrelated to (1)

Lead agencies and administrative arrangements for managing these pathways vary widely between countries. Many nations have not designated a clear lead agency. Where lead agencies have been determined by legislative mechanism, these are typically either the department responsible for shipping management and safety (including the application of other IMO conventions and instruments) or the lead quarantine agency.

Levels of collaboration and coordination among relevant agencies varies widely. Federated nations such as Australia and United States face additional complexities to provide uniform and coherent strategies for international and domestic shipping. Legislation and administrative arrangements in most APEC countries and those participating in the GloBallast Programme can be found in Williamson *et al* (2002) and Appendix A respectively.

5.2.2 Components of Strategy

Despite the range and current flux of administrative arrangements noted above, there has been generally wide recognition and agreement that best practise management strategies for marine bioinvasions need to contain the components shown in the following table.

Strategy	Component	Purpose
Contingency planning	Form Task Group Logistics and funding Information collation Cost benefit analyses	Avoid crisis management Improve preparedness Develop rapid response toolbox Improve priority decision-making
Prevention	Pre-border Border	Identify and prioritise all pathways which transfer targeted known/suspect pests Reduce size / number of pathways Intercept and remove targeted organisms from priority pathways
Surveillance	Active Passive	Early detection of presence and spatial extent of incursions at high risk locations Enhance area and level of vigilance
Response	Confine Eradicate	Quarantine secondary pathways to prevent spread Eliminate all individuals in population
	Control Contain Exclude	Limit size of non-eradicable population Limit spread of non-eradicable population Prevent entry of non-eradicable population into high value / sensitive areas
Do nothing / Last resorts	Mitigate Monitor Research	Compensate, ameliorate ecological and economic impacts Detect changes in population size and spatial area Improve knowledge base of species characteristics and impact mechanisms Screen for possible biological control agents and methods

As noted in Section 5.1, no biosecurity programme should overemphasise border protection, and effective surveillance and incursion response programmes must be put in place. In the case of New Zealand, surveillance experienced a decline in the share of biosecurity resources funding during the 1990s. By 2002, surveillance was reported to have fallen to $5-10 million out of MAF's total biosecurity budget of $80 million (Nimmo-Bell 2002). A major review and upgrade of the NZ biosecurity strategy, decision-making processes and budget allocations was undertaken during 2003, with several reports following a summit held in Wellington in October 2003 (available through NZ-MAF and NZ-MFish links, in Appendix A).

5.2.3 Preparedness and Decision-Taking Requirements

To ensure resources and funds are allocated effectively when implementing the strategy, managers and their task groups need to review, prioritise and target the following:

- High risk primary and secondary pathways.
- High-risk known or suspected marine pest species.
- Which previous incursions warrant continuing pathway/population control responses.
- When to mount an eradication or control response for a detected new incursion.

These are complex decisions that need to take into consideration the extent of area/s infested, known or suspected impacts, the environmental value of habitats invaded, possible economic disruptions and ecological side-effects. A number of methods are available, based on risk assessment procedures, cost-benefit analysis and/or multi-criteria testing (e.g. Nimmo-Bell 2002, Williamson *et al* 2002; NIMPIS links in Appendix A). A risk assessment provides a formal framework to weigh the relative costs, benefits and further risks of a continued pest incursion, against those of an eradication or control attempt. However these take time to complete. A decision-tree to facilitate decision-making during a rapid response to a marine NIS incursion has been developed by CSIRO (Figure 7).

Eradication attempts need to be early and vigorous. It is important that implementation of appropriate control measures should not be delayed, since a rapid response to an incursion is the next most economic approach to prevention for a known or suspected harmful species. Without contingency planning, hurried decisions taken in a 'crisis' situation may well be subjective owing to the little time available for deciding on what type of response and control mechanism/s should be mounted.

5.2.4 Value of Contingency Planning

The decisions to respond to a reported incursion and to decide if eradication should be attempted are not easy. Contingency planning allows a 'Rapid Response Plan' to be developed and put in place before the crisis arises. Factors that increase the ability to make an appropriate decision include:

1. Early and accurate detection of the species incursion (via a pre-arranged Surveillance-Response connection)
2. Pre-existing Rapid Response arrangements, including a pre-agreed funding allocation to cover initial decision making, authorisations and logistical needs.
3. Legal mechanisms to allow effective quarantining of the area (i.e. to reduce spread and 'buy time' for taxonomic confirmation, knowledge gap-filling, eradication/control decision-taking, and engagement of logistics for same).
4. A monitoring capacity to confirm if the species is indeed restricted to quarantine area
5. Pre-knowledge of its lifecycle, physiology and environmental tolerances
6. Knowledge of the treatment options available for eradicating/controlling the species or closely-related taxa
7. Pre-determined supportive network of technical, field, administrative, funding and legal contacts for implementing an eradication or control campaign;
8. Sufficient resources to monitor and review progress (for modifying or terminating the eradication campaign)

Developing a Rapid Response Plan requires review of the marine and estuarine invasive species eradication, control and mitigation literature, development of a rapid response decision-taking system (decision-tree), and listing a 'toolbox' of the control measures and associated legal considerations/actions required for mounting each option[15].

Eradication technologies need not be highly species specific provided their impacts on non-target species are limited by the size of the NIS infected areas. The decision to eradicate a potential marine pest species requires careful evaluation with respect to:

- the balance of the benefits and hazards from using the available eradication method/s,
- the level of effort, funds and disturbance to stakeholders to achieve eradication success
- the benefits and hazards of leaving the potential pest to spread in either:
  - an unrestricted fashion;
  - a controlled fashion; or
  - a controlled fashion supported by mitigation actions.

Once a pest becomes more widespread, control techniques need to be more specific and carefully applied to maintain cost-effectiveness and avoid serious impacts to native species. The point where eradication is deemed impractical using currently available technologies is the point where long-term control becomes the preferred response. Long term control often warrants an Integrated Pest Management program (IPM) aimed at reducing, constraining and maintaining the population/s to levels that avoid unacceptable economic or ecological impact.

Box 5: Treatment options in the interactive 'Rapid Response Toolbox' of the NIMPIS system

Australia's Rapid Response Toolbox is a web-based database of control options that was developed following elimination of the black-striped mussel (*Mytilopsis sp.)* at the Darwin marinas in 1999. Lessons from this exercise showed the need for agencies to have ready access to information on potential control options for introduced marine species, in order to better respond to future incursions.

The NIMPIS system maintained on the CSIRO website now provides control option information for the 14 species first designated as targeted 'marine pests' by Australia (*Alexandrium catenella, Alexandrium minutum, Alexandrium tamarense, Gymnodinium catenatum, Asterias amurensis, Carcinus maenas, Corbula gibba, Crassostrea gigas, Musculista senhousia, Sabella spallanzanii, Undaria pinnatifida, Vibrio cholerae, Mnemiopsis leidyi* and *Potamocorbula amurensis*). Other species have been since been added, including *Mytilopsis sallei, Caulerpa taxifolia* (aquarium strain), *Codium fragile ssp. tomentosoides, Sargassum muticum, Balanus eberneus* and *Perna viridis.*

Information on potential control options such as application methods and rates, health and safety information and the side effects and constraints is provided within the web-based toolbox. The toolbox also lists contact details of the relevant Commonwealth and State Authorities and addresses legal issues. There is also some information included for other closely related species or species that are very similar functionally, for which control options can be extrapolated to the target species. Production of this web-based toolbox involved an extensive review of the terrestrial, freshwater and marine control and mitigation literature (Appendix C), and examination of the success and failure of various methods. This culminated in the development of a rapid response decision tree (Figure 7) and a report on the control options reported in the literature (Appendix A).

While the Rapid Response Toolbox has been incorporated into NIMPIS, the control information remains limited. Control options for the 70+ other potential and 'next pest' species currently listed in the NIMPIS database may be added in the future. Some of the available control options which may be relevant for these or other pest species can be examined at higher taxonomic or functional levels (e.g. by searching for control options for 'Crassostrea', 'Mytilidae' or 'mussels'). To search the Rapid Response Toolbox for control options go to: http://crimp.marine.csiro.au/NIMPIS/toolbox.htm. References and publications collated for the control options are listed in Appendix C and can also be downloaded from: http://crimp.marine.csiro.au/NIMPIS/RefDetail.asp?bib=61&navbar=cont

[15] Regulations used in Australia for the availability and use of chemicals for marine pest control in the marine and estuarine environment are summarised in Appendix B.

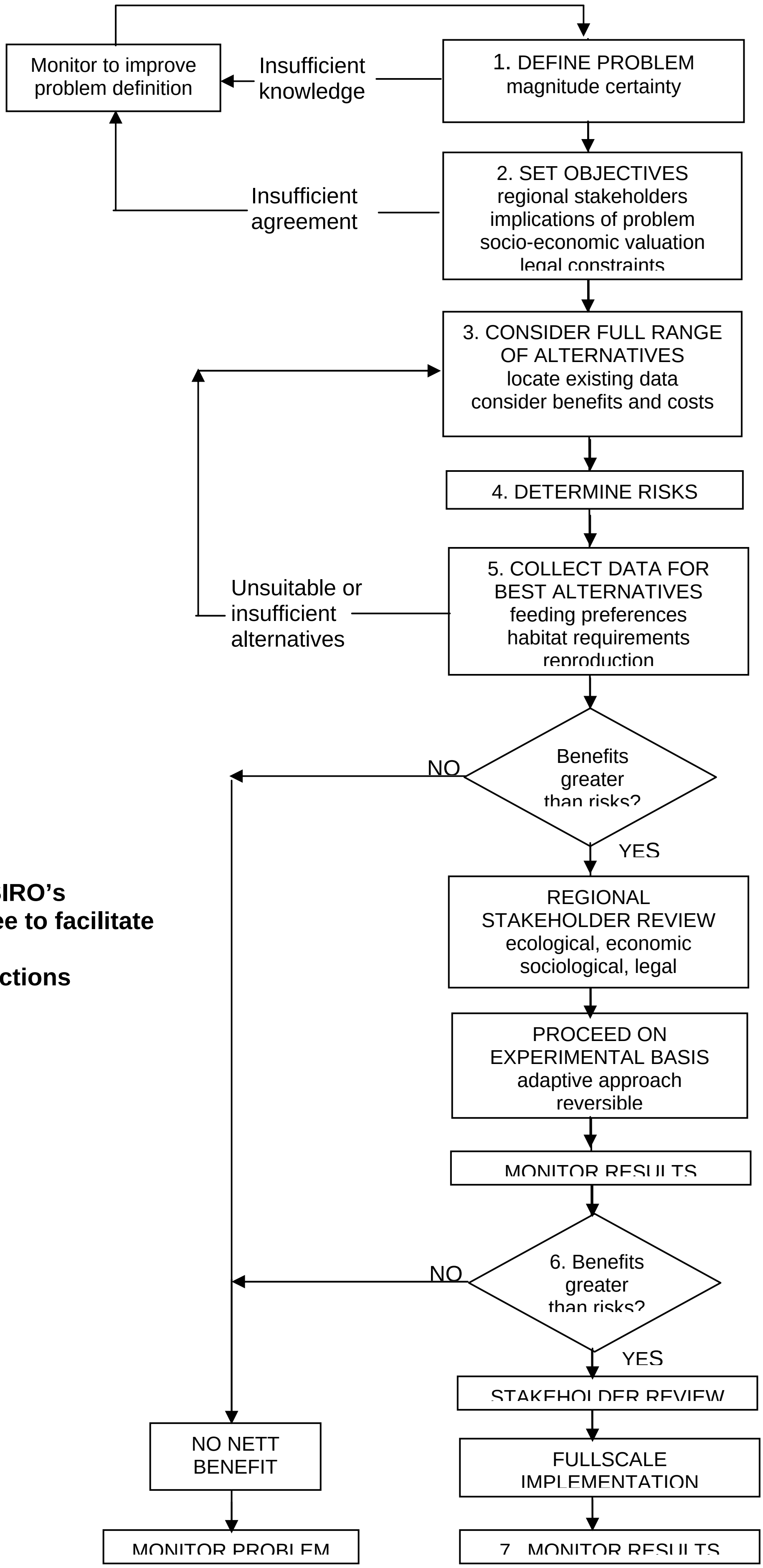


Figure 7: CSIRO's Decision Tree to facilitate Rapid Response Actions

5.2.5 Value of Effective Surveillance

Owing to the lack of reliable border control techniques, detecting incursions in the early stages is critical. Successful eradication can usually be achieved for populations if found in a restricted area soon after establishment, so the early recognition of NIS greatly increases the ability to mount a successful rapid response (Section 5.1.2.3). While ports are a key entry point for marine NIS, secondary incursions may occur in areas far from ports via local vectors (Section 3).

Local communities and marine industry stakeholders can play a role, if provided appropriate information, encouragement and support from professional biologists (Sections 2.5, 4.9). An Australian programme encouraging public awareness is being funded and managed by Commonwealth and State Government agencies, with assistance from industry groups, port authorities, research agencies, existing marine monitoring networks and community groups. The programme aims to facilitate early detection of new invasive species by developing knowledge on marine NIS already present in Australia via awareness raising, education and assisting specific stakeholder groups such as port authority personnel and slipway operators to become active watchdogs.

5.2.6 Confinement

The first act in dealing with a known or suspected marine pest that is detected in restricted localities is to survey and delineate the infected area/sand, then take ‘quarantine’ actions to remove vectors that could assist its spread. After the incursion has been confined, the task group can focus on reviewing eradication or other control measures, including mitigation and monitoring to confirm there are no other areas with as yet undetected populations.

5.2.7 Eradication

“*Eradication is the elimination of the entire population of an alien species, including any resting stages, in the managed area*” (GISP 2001).

Eradication is the appropriate response when a known or suspected marine pest is discovered and found to be restricted to small area/s. To have any chance of success, the decision to eradicate must invoke a rapid and coordinated response during what is typically a short window of opportunity (i.e. before the population has the chance to expand and disperse into new areas via broadcast spawning and secondary pathways).

Eradication of marine NIS incursion have been achieved using mechanical, chemical and biological control methods, including habitat alteration (e.g. Box 7 in Section 5.2.8). However, the suite of available treatments is limited, and development of specific treatments to avoid unacceptably high collateral damage to native biota and ecosystems typically requires much time and a thorough understanding of the life-cycle, physiology, habitat preferences and ecology of the NIS in question. Such detailed knowledge is rarely available, even for many well known marine invaders.

The cost and side effects of existing physical and chemical technologies constrain what can be achieved by an eradication program. Ideal eradication methods would be highly selective, have no long-term effects on the environment, human or other life, and be cost-effective and easy to use. This is rarely the case and managers considering eradication are typically faced with some difficult choices. The perceptions, expectations and resources of the various stakeholders and interest groups may significantly influence the discussion, choice and application of the selected technology. Decisions may be influenced by the differing weights of arguments made by competing interest groups, according to actual or perceived economic impacts of the proposed method and current environmental values.

Without failed quarantine efforts, eradication would not required to be attempted; without failed eradication, control and mitigation programs would not be needed. Failure is not necessarily an indictment on the choice of action, particularly if the decisions taken at the time were based on available information and adequately implemented.

While the success of an eradication or control program can be evaluated while underway or after completion, there is often insufficient economic, environmental and social information for evaluating its advisability before inception. One uncertainty may be whether the incursive species will actually spread widely and become a serious pest. Some introduced species do not seriously disrupt their new ecosystem, and may remain in degraded environments less suited for native species or become accommodated in the existing assemblages through niche shifts and other mechanisms (e.g. Moyle 1999, Section 2.4). In the case of the comb jelly invasion (*Memniopsis leidyi*) in the Black Sea, the ‘do-nothing’ option avoided the need to risk releasing doubtful biological control agents and was followed by the subsequent appearance of *Beroe ovata* which solved the biological control question (Section 4.10).

5.2.8 Treatment Methods

The first step in developing an effective eradication or control strategy is to check literature and database sources to accumulate as much information as possible about management options for this species. Managing an invasive species is not the management goal, but a tool in the process to maintain or achieve resource management goals such as habitat restoration, a sustainable fishery or ecotourism sector, the preservation of an undisturbed ecosystem, etc. In most cases, best practice management of an invasive species involves an integrated management system tailored to the species and location. Thus, it is important to accumulate the available information, assess all potential methods, and use the best method or combination of methods to achieve the target level of control.

Four approaches have been applied for both the eradication and control of pest species:

- mechanical/physical (e.g. removals by hand, divers or mechanical harvesting);
- chemical (e.g. chemical dosing, toxic baits, application of an inorganic or organic herbicide, larvicide or other pesticide);
- biological – such as use of a target-specific pathogen, parasite, predator, biopesticide (e.g. *Bacillus thuringiensis* [Bt]), genetic manipulation, reproduction manipulation or habitat modification (e.g. salinity change by salt dosing or freshwater inundation); and
- Integrated Pest Management (IPM).

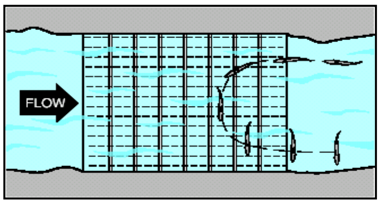
5.2.8.1 Mechanical and Chemical Treatments

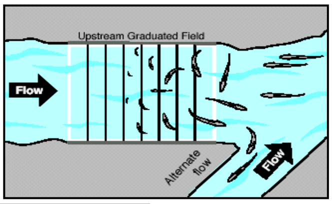
Various mechanical and chemical treatments have been used by natural resource management and conservation agencies in various countries in attempts to eradicate or control invasive species, and there are differing rules on the use of some of these treatments according to local legislation. The CSIRO Rapid Response Toolbox, the GISP database and other websites and published documents provide information sources on this topic (Appendices A and C). It is also worth noting that national and/or regional legislative instruments pertaining to the permissibility and specific method/s of a treatment can be present in occupational health and safety and public health regulations as well as those pertaining to environment protection (Appendix B).

Treatments used for the eradication or control of freshwater species in lakes and waterways have some application for marine situations such as coastal lagoons, barred estuaries and enclosed breakwater harbours. These include poisons such as rotenone used for fish, specific larvicide (TFM) for lampreys, and aquatic weed mechanical harvesting or herbicide spraying. While herbicides typically used for freshwater plants (e.g. glyphosphate, 2,4-D) do not kill algae species, there are several algicide alternatives. Second generation electrical barrier systems hold less promise for containing the spread of introduced migratory species in marine or brackish-water areas owing to the problem of salinity conductance which greatly reduces their effectiveness and requires dangerous, costly power levels to overcome. However they may be useful for controlling spawning migrations of unwanted anadromous and diadromous non-native fishes in particular watersheds (see Box 6).

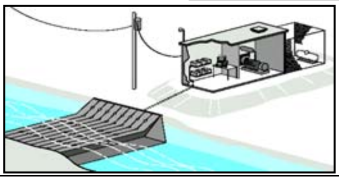
Box 6: Developments in Electric Barrier Methods

Since the first attempts in the 1950s-1960s (Section 3.1), there have been several improvements to the efficiency of electrical barrier designs for preventing non-native migratory fishes from entering rivers and watersheds for spawning and spread (e.g. sea lampreys, salmonids, Asian carp etc). Systems trialled in various North American watersheds during the 1990s typically use a Graduated Field Fish Barrier (GFFB; as developed and promoted by Smith-Root, Inc). The GFFB provides a substantial improvement over the earlier alternating current and single-field direct current barriers. By using an electrical array mounted in an insulated concrete pad to produce the graduated field, they can also be installed without posing a major navigation obstacle and are less prone to debris damage. As a fish swims into the electrical field, the increasing voltage inhibits the swimming ability of the fish and the fish are quickly swept clear of the field by water flow. The most efficient electric field pattern for blocking or guiding fish has electric field lines running parallel to the water flow. The advantage of this parallel field orientation is that fish which turn crosswise to the electric field receive almost no electric sensation or muscle paralysis. Fish learn very quickly that by turning side ways to the flow they minimize the effect of the electric field. In this orientation, upstream migrating fish are swept clear of the field by the water flow. The figures below show reactions of migrating fish when they try to migrate across a GFFB. In slow or static water a high percentage of fish learn to turn and swim away from the electric field. However water velocities >0.6 metres/second are required to avoid fish kills by helping to quickly sweep the fish downstream and out of the field. Details on designs and locations of of electrical barriers trials in the US are available as downloadable files from www.smith-root.com.





Figures from Smith-Root website



5.2.8.2 Biological Treatments and Integrated Pest Management

These are organisms or agents which are typically sourced from the natural range of the harmful species and have a very high level of target specificity. By exerting negligible side effects on native species, ecosystems and human health, these biological controls can be used in all sensitive areas to provide an efficient and self-sustaining long term response. The main disadvantages of biological controls are:

- the time and expense required to identify, screen and test candidate control agents;
- the time required for the released agent to multiply and cause the required effect throughout the targeted population;
- uncertainty about the level of control the agent will ultimately bring to bear on the targeted population;
- the potential for the agent to exert an unexpected effect on native species or communities; and
- the population regulation mechanism underlying the principle of biological control, which does not anticipate eradication but reduces the invading population density and fitness, with the prey/host or predator/parasite relationship achieving a dynamic balance.

Depending on the situation, eradication of pathogens and parasites may focus on isolation, treatment or culling of infected hosts (if the latter comprise cultured populations contained in ponds or open water pens), and/or the culling of local wild populations. Confirmatory post-eradication monitoring should be implemented as a routine, precautionary measure.

Habitat modification includes altering the characteristics of the water column as well as modifying the benthos (e.g. increasing the salinity to increase the osmotic stress and reduce the growth rate of the aquarium strain of *Caulerpa taxifolia*, as has been used for coastal lagoons in South Australia (Box 7).

Integrated Pest Management (IPM) frequently forms the basis of control programme approaches. IPM arose from terrestrial programmes where environment and human health issues arising from the long term use of broad spectrum pesticides for controlling agricultural pests led to the adoption of mixed treatment strategies. Thus IPM typically employs one of several pre-agreed mechanical, chemical and biological methods depending on the locations and circumstances. Optimum control strategies are likely to be location specific, and need to be trialled and fine-tuned for different areas. If the introduction is an edible shellfish or finfish, one control method in the toolbox is targeted recreational and commercial fishing.

BOX 7: TREATING *CAULERPA TAXIFOLIA* IN SOUTH AUSTRALIA

An invasive population of the seaweed *Caulerpa taxifolia* was discovered near Adelaide in South Australia in March 2002. Surveys established the incursions were limited to three localities: an urban wetland (West Lakes), part of the upper Port River, and an isolated small patch further downstream in Eastern Passage (Barker Inlet).

West Lakes is an artificial wetland located in an urbanised coastal area near Adelaide and was the site of the largest incursion. West Lakes has a surface area of approximately 1.2 km^2 and holds approximately 3 gigalitres at usual fill levels. Most of West Lakes is relatively shallow but in one area extends to approximately 6 m deep. The system drains into the infected area of Port River, and water exit/entry can be controlled for managing lake levels. In the upper Port River (which is a tidal estuary system), the weed was present along an approximately 2 km long section, with most in the southernmost 800 m stretch. The Eastern Passage outbreak comprised a small patch located approximately 7 km further downstream from the nearest edge of the upper Port River incursion area.

After information exchanges and consultations with managers and researchers engaged in *Caulerpa* incursions in coastal estuarine areas of New South Wales, the South Australian government agency responsible for responding to aquatic invasive species decided to eradicate the outbreak in West Lakes by reducing its salinity. This was achieved by diverting very low salinity urban storm water, sourced from the Torrens River catchment. A successful eradication was achieved during 2003 by reducing bottom water salinity to values to ~10 PSU and maintaining these for several weeks (longer in some areas), To date this treatment appears to have been successful.

The small patch located in Eastern Passage was treated by smothering with heavy duty PVC sheet which was pinned down before injecting with chlorine. Large scale removal of the weed's biomass in the upper Port River was achieved using a large, diver-operated airlift connected to barge-mounted settlement and filtration systems. Significant portions of the Port River incursion were also treated using smaller portable suction devices and by smothering with black PVC Further large scale treatment strategies for this area are currently being developed and assessed. Regular extensive surveys throughout the area have located no other incursions to date.

(from communications and information kindly supplied by John Gilliland, Primary Industries and Resources South Australia (PIRSA), Adelaide, Australia [Gilliland.John@saugov.sa.gov.au])

5.2.9 Control, Containment and Exclusion

Control aims to avoid unacceptable economic and/or ecological impacts by reducing the abundance of the introduced population/s to levels below a pre-determined threshold. Since control typically offers more practical, less damaging and (in the short-term at least) more affordable options than eradication, it has been a preferred method for many terrestrial and aquatic pests (mostly freshwater invasive plants in the case of the latter). Its funding can also be varied from year to year depending on the perceived significance of the impacts to the affected environment, industry and/or public. However all control programmes require long-term funding and commitment, even if they are based on a classic self-sustaining biological control organism (monitoring is required to confirm the efficacy of the control and lack of resistance build-up in the remaining individuals). In the long run, an effective control programme may become more expensive than a successful eradication campaign.

Containment is one of several control actions. The aim is to restrict an invasive species to a limited geographical range, and methods include those used for prevention of new incursions and eradication. The population is suppressed along the border of the defined containment area/s, with strict controls applied to vectors causing spread of individuals beyond these areas. Individuals and founder populations discovered outside the control areas need to be detected and eradicated promptly. Containing any aquatic species to one or more defined areas can be difficult and requires regular monitoring and consistent application of the containment measures. Containment is more likely to be achieved in locations that contain isolated or near-isolated water bodies, and/or if the fecundity and dispersal mechanisms of the targeted species can be limited via other control measures.

Exclusion aims to protect environmentally important areas by preventing the ingress of the targeted species. In the case of exclusion efforts made in the Mediterranean (against *Caulerpa taxifolia*) and Northern Ireland (*Sargassum muticum*), these have been made to protect marine reserve areas that contain high biodiversity and species highly susceptible to the pest species.

5.2.10 Mitigation, Monitoring and Research

These are 'last resort' strategies to find the best way in which to adapt to the ongoing presence of the unwanted NIS, with the focus on reducing its impacts on native biota and ecosystems. Mitigation activities may not directly affect the invasive species but focus on affected native taxa, as may be used for species with high commercial or conservation value. This approach can be applied at various levels. Its most extreme form involves the translocation of endangered species to ecosystem/s where the invasive species is absent or already eradicated. Mitigation can be labour intensive and costly, and may be treated as an intermediate measure that is taken in tandem with eradication, containment or control.

5.3 VECTOR-SPECIFIC MECHANISMS AND CODES

5.3.1 Commercial Shipping Vector

Because shipping and mariculture activities have been responsible for the majority of primary invasions and/or subsequent spread by secondary pathways, much effort in the 1990s has been placed on developing voluntary guidelines or prescriptive (mandatory) regulations aimed at improving the management of ballast water, hull fouling and the importation of seed stock and nutriments for mariculture.

Shipping is one of the most globalised of the world's industries, and the only effective way to address this vector is through the standardised international system functioned through the United Nation's IMO for over 50 years. The avoidance of unilateral responses by individual states is critical to the success of any regulatory regime that applies to shipping.

In November 1997, IMO member nations adopted Assembly Resolution A 868(20) *Guidelines for the Control and Management of Ships´ Ballast Water*. These guidelines require ships to possess a Ballast Water Management Plan which identifies (a) appropriate ballast water treatment options specific to its vessel type, design and trading operations (currently BW exchange if and when safe and feasible), and (b) locations of ballast water sampling points for monitoring and sampling purposes by Port States.

The current IMO BW Guidelines also recommend Port State authorities should carry out risk assessments, implement BW monitoring and control activities, and develop contingency plans and BW management alternatives as and where appropriate. The GEF/IMO/UNDP funded GloBallast Programme has also been promoting the adoption of the standardised BW management regime throughout its activities.

Through sub-groups working under IMO's Marine Environment Protection Committee (MEPC), IMO member countries have continued developing technical guidelines for the international Convention on Ballast Water Management. This convention, to be adopted by the Diplomatic Conference in London (February 2004), is summarised in Box 8. Due to the relatively slow pace in the development and future implementation of the ballast water convention, many countries and sub-national jurisdictions have begun implementing national, provincial or port regulations under new or existing legislation.

Box 8: IMO Convention on Ballast Water Management

Requirements:

1. Existing ships (those built before 1 Jan 2009) will be required to begin conducting mandatory ballast water exchange at the date of entry into force of the convention.
2. New ships with a ballast capacity of less than 5000 m3 will be required to use a treatment method to meet a strict discharge standard from 1 Jan 2009.
3. New ships with a ballast capacity of 5000 m^3 or more will be required to use a treatment method to meet a strict discharge standard from 1 Jan 2012.

The tonnage delineations account for the likelihood that treatment technologies will probably be developed for small amounts of ballast water initially then 'scaled-up' after the former have been proven.

Grandfathering: Limited grandfathering for existing ships was accepted into the Convention. Further, in an unusual step there was also an introduction of grandfathering for certain 'new' ships. Details of the grandfathering provisions are as follows:

Existing ships (built before 1 Jan 2009):

1. **Existing ships with a ballast capacity between 1500m3 and 5000m3, inclusive, can use ballast water exchange until the first scheduled intermediate or renewal survey (which ever comes first) after 1 Jan 2014, after which time they must use a treatment method to meet the strict discharge standard.**
2. Existing ships with a ballast capacity less than 1500m3 and greater than 5000m3 can use ballast water exchange until the first scheduled intermediate or renewal survey (which ever comes first) after 1 Jan 2016, after which time they must use a treatment method to meet the strict discharge standard.

The tonnage delineations are to give small ships and large ships more time because of the reason above (for smaller ships because initial equipment may be large and difficult to fit on existing small ships].

New ships (built after 1 Jan 2009):

Ships constructed in or after 2009, but before 2012, with a ballast capacity of 5000m3 or more can use ballast water exchange until the first scheduled intermediate or renewal survey (which ever comes first) after 1 Jan 2016. After this time they must use a treatment method to meet the strict discharge standard [again, due to the likelihood those treatment technologies will not be capable of such large volumes initially].

BALLAST WATER EXCHANGE

1. Ships using ballast water exchange can continue to use three times the volume of each tank as being acceptable in terms of meeting a 95% volumetric exchange.
2. Any ships wishing to use less than three times the volume of the tank would need to prove that a 95% exchange is still being achieved.
3. Exchange should be conducted 200 nm from nearest land and in 200 m depth.
4. Where this is not possible, 50 nm and 200 m depth is acceptable.
5. Where this is not possible a Port State may designate areas where ballast water exchange should/can be done.
6. Ships will not be required to deviate or delay in order to conduct ballast water exchange.

While it is not expressly stated in the Convention, the interpretation of above provided by the Chairman of the Committee was that, in such circumstances, the ship could discharge the un-exchanged ballast water in port upon arrival. Several countries indicated that this was their interpretation. Such advice being provided by the Chairman will certainly lend weight to ensuring appropriate reflection of the above requirement when Australia (and other countries) begins drafting the domestic legislation to give this Convention effect.

BW TREATMENT STANDARD AND ENTRY INTO FORCE
The strict treatment standard is a combination of a number of organisms above and below a particular size. Full details are in Convention. Ballast water exchange will not be able to be used to meet the treatment standard, in other words, ballast water exchange is going to be phased out completely. There is no treatment technology currently available to meet the standard. All fixed dates in the Convention are subject to a review of the availability of appropriate treatment technology. The review must be held before the end of 2005. A negative outcome to the review will result in an extension to the dates listed above and another review scheduled. The Convention will enter in force 12 months after 30 States, with fleets representing 35% of the gross tonnage of the world's merchant shipping have signed the Convention. There is still substantial work to be done with ten sets of guidelines to be developed.

Most are generally consistent with the current IMO Guidelines, while some have imposed different requirements, sometimes to the concern of affected parts of the shipping industry:

Argentina: Direccion Nacional de Sanidad de Fronteras, del Ministerio de Salud Publica (Ministry of Public Health - Quarantine Authorities) – Buenos Aires.

Australia: Australian Quarantine & Inspection Service (AQIS) – all ports.

Brazil: ANVISA: Ballast water reporting requirements – selected ports

Canada: Canadian Coast Guard (CCG) – all ports. Special requirements in the Great Lakes and at Vancouver (Vancouver Port Corporation; www.portvancouver.com)

China: Maritime Safety Administration - Ballast water reporting requirements at Dalian and other selected ports.

Chile: Chilean Navy, Division for Maritime Territory and the Merchant Marine (Maritime Safety and Operations Department) – all ports.

India Ministry of Shipping: Ballast water reporting requirements at Mumbai and JNPT ports.

Iran: Ports and Shipping Organisation: Ballast water reporting requirements at Khark Island Oil Terminal and selected other ports

Israel: Ministry of Transport, Shipping and Ports Administration – all ports.

New Zealand: Ministry of Fisheries – all ports (http://www.fish.govt.nz/sustainability/ballast/ballast_health.html)

South Africa: SAMSA and National Ports Authority: Ballast water reporting requirements at Saldanha Bay and selected other ports.

Scotland (UK): Orkney Islands Council - Scapa Flow, Orkney Islands

United States: Coast Guard (USCG) plus special requirements for Great Lakes and Hudson River above George Washington Bridge
California State Lands Commission - all ports in California.
Washington State - Puget Sound

5.3.2 Fishers, Boat Owners and Mariculture operators

The following guidelines and prescriptions for reducing the spread of introduced *Codium*, clubbed sea squirts and green crabs in the Gulf of St Lawrence were distributed by the Canadian Department of Fisheries and Oceans in June and October 2003 (http://www.glf.dfo-mpo.gc.ca/sci-sci/inva-enva/index-e.html)

For fishers:	Never release live bait, aquarium fish, crayfish, or plants into the water. Clean clams or other shellfish in the water where they were collected. Move them with a minimum amount of water. Learn to identify invasive species in your area and report any sightings.
For trailered boats:	Wash boat, anchor, trailer and other equipment with fresh water and/or spray with undiluted vinegar. Remove any plants or animals. Drain water from your boat motor, bilge and wells. Dry equipment completely if possible.
For larger vessels:	Use anti-fouling paint to reduce settlement of organisms on the hull. Don't take on or release ballast water in port, near aquaculture facilities, or at night.
For shellfish farmers:	(23-10-03) Shellfish lines and related gear covered with invasive clubbed tunicates present handling difficulties and increased costs to the shellfish industry. The tunicates will also attach cultured mussels, oysters, gear and vessels. All commercial fishers and recreation boaters need to be aware that spreading can take place in this fashion. Investigations to ascertain if other areas are affected are ongoing. A license will be required to transfer any bivalve molluscs out of, within, or between regions in the southern Gulf of St Lawrence, including all estuaries, tributaries, rivers and bays in the designated areas. Persons finding the clubbed tunicate in other waters or attached to the hulls of their vessels, are requested to notify either DFO, the Provincial Department of Fisheries, Aquaculture and Environment, or anyone in the aquaculture industry.

6. SUMMARY CONCLUSIONS AND REPORT LIMITATIONS

The science and management of invasive marine species incursions into coastal, estuarine and inland water ecosystems remains in its infancy. Knowledge and modelling of the various factors influencing the marine bioinvasion processes remain incomplete. Many terms remain ambiguous and form the source of potential confusion and misunderstandings, particularly for newcomer managers or researchers. Only a handful of successful eradication cases of introduced marine species have been reported from around the world, many substantially assisted by serendipitous circumstances rather than forward planning and use of sophisticated control options.

Complete eradication has only been achieved when the introduction was recognised at the early stage of colonization (i.e. where the founder individuals or population had a limited spatial distribution). At such early stage eradication methods need not be highly sophisticated or species specific since their possible damage to non-target species is limited to a small area. For these reason strategies addressing invasive marine species invariably emphasise the value of prevention and surveillance. While much emphasis has been placed on prevention it is important to recognise that an equally high level of active and passive surveillance is required. This is because it is impossible to provide completely secure pre-border and border controls without inordinate and costly interruptions and delays to commercial and recreational vessel movements and other coastal activities. Future developments in surveillance techniques and tools such as portable gene probe/protein recognition systems, highly targeted species/habitat surveys and more sophisticated and robust settlement monitoring devices, all offer the promise of increasingly cost-effective surveillance mechanisms.

Once an introduced marine species has a achieved a large, well established population, and/or has already dispersed by self-mediated or human-assisted pathways across a wide area in relatively low numbers, eradication with present technologies typically becomes impractical. In these cases, the remaining options are to contain the population’s size and reduce its rate of spread as much as practicably possible, and to implement a strategy for lowering its existing or feared impacts to some level of societal, economic and ecological acceptability. Such actions typically involve identifying the key vectors and pathways and implementing controls, identifying and implementing best available population reduction measures, devising an impact mitigation program, and funding research for key gap-filling, improved understanding and/or the screening of possible specific biological controls.

When eradication efforts are deemed unworkable a biological control involving the deliberate introduction of a native predator, parasite or pathogen (or genetic manipulation), is often portrayed as the best option for dealing with unwanted established populations. While biocontrols have been used in terrestrial systems (with results historically ranging from disastrous to highly successful), it is more difficult to ensure their efficacy, host-specificity and safety for marine species that are established in relatively unconfined and typically highly connected estuarine and coastal waters. Similarly, installation of physical or electrical barriers, use of baits, habitat modifications and/or manipulation of prey or nutrient requirements are more difficult and expensive to achieve in aquatic than terrestrial systems.

The selection, testing, evaluation and risk assessment work which is required before any biocontrol organism can be released, typically involves considerable basic research and rigorous procedures. Development of innovative solutions and techniques to obtain highly specific biocontrols may well emerge from the methods which are now used to produce and test genetically modified organism (GMOs) and other transgenic forms.

URS Australia Pty Ltd prepared this mini-review during December 2003 for the use of the GISP Secretariat, in accordance with the purpose and scope of work outlined in the proposal dated 24 November 2003, and following accepted consultancy practices and standards. The report is based on the information that could be collated and reviewed during the relatively short preparation schedule. Because of the very short time frame, its occurrence over the December/New Year vacation period and the budget limitation, it was not possible to collate up-to-date information from all known sources. This should be noted by any future users of this review or its bibliography.

The methodology and information sources are outlined in this report, and URS has made no independent verification of this information beyond the agreed scope of works, and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as collated or provided to URS was false. No other warranty, expressed or implied, is made as to the professional advice included in this report.

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APPENDIX A

Bibliography of Database Resources, Management Practises, Legislation and Agencies & Organisations pertaining to Invasive Marine Species

MARINE TAXONOMY AND BIODIVERSITY DATABASE RESOURCES:

Online databases and information sources containing useful taxonomic data and knowledge have been collated by the US National Biological Information Infrastructure (NBII). Sites of interest and value to research and management of marine invasive species are as follows:

Integrated Taxonomic Information System (ITIS)

- ITIS - North America (English/French/Spanish languages)
- Biological Observations, Specimens and Collections (BiOSC) Gateway (ITIS - North America))
- Species 2000 The Global Taxonomy Initiative
- The Global Taxonomy Initiative: Shortening the Distance between Discovery and Delivery
- The Global Taxonomy Initiative: Using Systematic Inventories to Meet Country and Regional Needs

BioNET-INTERNATIONAL - The Global Network for Taxonomy (BioNET International is a global network for capacity building in taxonomy, enabling contacts with local networks and identification of regional expertise.

World Taxonomist Database (this global database of specialist taxonomists is maintained by the *Expert Centre for Taxonomic Identification* (ETI) in the Netherlands).

Directory of Research Systematics Collections (DRSC)

Taxonomic Resources and Expertise Directory (TRED)

Alphabetical List of Canadian Systematists TAXACOM: Biological Systematics and Biocollections Computerization Discussion List

Biological Nomenclature in the 21st Century - Proceedings of a Mini-Symposium (Univ. of Maryland)

Classification of Living Things - An Introduction to the Principles of Taxonomy Journey into Phylogenetic Systematics (University of California - Berkeley)

Tree of Life (Univ. of Arizona)

UCMP Taxon Lift (Univ. of California - Berkeley)

TreeBASE - A Database of Phylogenetic Knowledge

The DELTA System (DEscription Language for TAxonomy)

Codes of Nomenclature

Class Excercise: The "Nuts & Bolts" of Taxonomy and Classification (Miami of Ohio Univ.)
International Working Group on Taxonomic Databases (TDWG)

Natural Science Collections Alliance (formerly Assoc. of Systematics Collections)

Biodiversity Informatics

http://www.biodiv.org - Convention on Biological Diversity

The Species Analyst (Univ. of Kansas)

Tools & Resources for Systematics Research (Univ. Mich)

Viruses: International Committee on Taxonomy of Viruses

Bacteria: Bacterial Nomenclature Up-to-date
List of Bacterial Names with Standing in Nomenclature

Bacterial & Fungal Databases of CBS (Centraalbureau voor Schimmelcultures, Netherlands)

Protists: Tree of Life - Protista
Zoosporic Fungi Online

Fungi: Tree of Life - Fungi
Bacterial & Fungal Databases of CBS (Centraalbureau voor Schimmelcultures, Netherlands)
Fungi: Systematics (Univ. of California - Berkeley)
Taxonomy of Fungi in Glomales (Arbuscular Mycorrhizal Fungi)
Checklists of Lichens (Worldwide)

Plants: Tree of Life - Green Plants
Centres of Plant Diversity - The Americas
Euro+Med PlantBase - Information Resource for Euro-Mediterranean Plant Diversity
Families of Flowering Plants
A Guide to Botanical Nomenclature - A Tennessee Tutorial Index Herbariorum (Search the Database)
Index Nominum Genericorum (Plantarum)
The Index Nominum Genericorum (ING) (Plantarum)
Internet Directory of Botany
International Organization for Plant Information (IOPI)
The International Plant Names Index (IPNI)
Suprageneric Names Database (IAPT-MARY) Index Nominum Supragenericorum Plantarum Vascularium
International Working Group on Taxonomic Databases (TDWG)
PANDORA Taxonomic Database System
PLANTS (NRCS) Plant Systematics and Evolution - Links
Searchable FLORA EUROPAEA Database

Animals: The Animal Diversity Web
Tree of Life - Animals Internet Resources Guide to Zoology (BIOSIS)
Classification of the Extant Echinodermata (California Acadamy of Sciences) SCAMIT: Southern California Association of Marine Invertebrate Taxonomists
Crustacea.net - An Information Retrieval System for Crustaceans of the World
The Catalog of Fishes Online (California Academy of Sciences)
FishBase - A Global Information System on Fishes
NEODAT: The Inter-Institutional Database of Fish Biodiversity in the Neotropics

The NBII site also contains pages of links to individual museum and specimen collections, which can be accessed at: http://www.nbii.gov/datainfo/syscollect/collections.html

The *Integrated Taxonomic Information System* (ITIS; http://www.itis.usda.gov/index.html) is a North American oriented but comprehensive and authorative taxonomic database covering native and introduced microbes, fungi, plants and animals for much of the world.

ITIS comprises a partnership of United States, Canadian and Mexican agencies, with close ties to the UK hosted *Species 2000* (http://www.sp2000.org) and the *Global Biodiversity Information Facility* (GBIF; http://www.gbif.org). These and other database centres (below) have commenced collaborative planning to implement the *Global Invasive Species Information Network* (GISIN), with the objective of building a comprehensive and user-friendly knowledge base for all invasive species. Initial meetings are being coordinated by the US National Biological Information Infrastructure (NBII) and members of the Global Invasive Species Programme (GISP's Invasive Species Specialist Group; ISSG), and aim to reach an agreement on the types, formats and field names of invasive species information to be collected and shared among international, regional, national and provincial online invasive species databases, thus allowing common gateways for searching and comparing invasive species information stored around the globe (below). Expected outcomes from the 2003/2004 planning phase are:

- Creation of an online working group community for developing and maintaining GISIN.
- Agreement on common data types allowin global cross-searches for invasive species.
- Development and distribution of a toolkit and template for proposals to fund database modifications and linkage structures.
- Generation of an annotated list of links to all online invasive species databases.
- Workshop reports, including results of a participants survey indicating the current regional status of invasive species information.

An invasive species 'information community' is being created within the NBII information portal (http://my.nbii.gov) to facilitate the planning phase.Invasive species information experts who cannot attend planning meetings are being encouraged to participate in the community discussion and help shape the network (invitations to join the discussion community and obtain "how to" instructions can be obtained from Nichole McNeely at nmcneely@usgs.gov, placing GISIN in the email subject line). Requirements sought for current invitations (1/2004) are:

- Expertise in invasive species information management or database development.
- A good Internet connection.
- A desire to help make GISIN a reality.

Further information can be sought from the current organizing committee and planning team listed in the following table:

Annie Simpson, Chair National Biological Information Infrastructure asimpson@usgs.gov	John Pickering DiscoverLife pick@discoverlife.org
Michael Browne Invasive Species Specialist Group m.browne@auckland.ac.nz	Jim Quinn, Information Center for the Environment University of California at Davis jfquinn@ucdavis.edu
Bonnie C. Carroll Information International Associates, Inc. bcarroll@infointl.com	Michael Ruggiero Integrated Taxonomic Information System Ruggiero.Michael@nmnh.si.edu
Vishwas Chavan, National Chemical Laboratory (NCL) Centre for Biodiversity Informatics, (Information Division), Pune, India vishwas@ems.ncl.res.in	Greg Ruiz Smithsonian Environmental Research Center ruizg@si.edu
Jeffrey Fisher U.S.Department of State, OES FisherJP@state.gov	Soetikno Sastroutomo CAB International, Malaysia s.soetikno@cabi.org
Mark Fornwall USGS, Pacific Basin Information Node Mark_Fornwall@usgs.gov	Silvia Ziller, Instituto Hórus The Nature Conservancy Brazil sziller@onda.com.br
Pam Fuller USGS Non-Indigenous Aquatic Species database Pam_Fuller@usgs.gov	Marcos Silva, Secretariat of the Convention on Biological Diversity marcos.silva@biodiv.org
William Gregg US Geological Survey William_Gregg@usgs.gov	Tom Stohlgren US Geological Survey Tom_Stohlgren@usgs.gov
Andrea Grosse IABIN (Western Hemisphere) Invasives Information Network (I3N) agrosse@usgs.gov	Hans Svart Danish Forest and Nature Agency hes@sns.dk
Sergej Olenin Klaipeda University, Lithuania serg@gmf.ku.lt	Yan XIE Chinese Academy of Sciences, Zoology xieyan@public3.bta.net.cn

MARINE INVASIVE SPECIES - INTERNATIONAL AND NATIONAL RESOURCES

Web pages and databases containing variable types of information on the distribution, biology, vectors and management options of marine invasive species have been made available by many organizations. Hyperlinks to most of the known international, regional and national directories, databases and publication sources for marine species introductions are listed below.

International

Invasive Species Specialist Group (ISSG) – part of IUCN's Species Survival Commission.

Global Invasive Species Database (GISP)

Marine Invaders (UNEP)

International Maritime Organisation (IMO) – the IMO's Marine Environment Protection Committee (MEPC) has been responsible for developing the international convention banning TBT-based antifouling coatings and their 5 year replacement schedule (2003-2008), and the new convention on ballast water management.

Global Ballast Water Management Program (GEF/UNDP/IMO). This 2001-2004 programme has been implemented to assist six pilot countries in the main developing regions of the world improve their capacity to implement ballast water management measures and become regional centres for training and technology transfer. Its global list of Ballast Water R&D projects (PDF report) is at: http://globallast.imo.org/research

FAO's database on Aquatic Species Introductions (UN-FAO DIAS: Database on Introductions of Aquatic Species; this site is becoming out of date due to lack of maintenance).

ICES (International Council for the Exploration of the Sea, with links to the ICES Working Group on Introductions and Transfers of Marine Organisms: WGITMO). ICES continues to focus on marine biological and fishery issues in the Atlantic Ocean and European Seas.

IOC (UNESCO) (Intergovernmental Oceanographic Commission). IOC resources on Harmful Algal Blooms (HABs) can be accessed via links on its home page, including materials from its HAB programme and the IOC's Science and Communication Centre on Harmful Algae. These include downloadable workshop reports, the newsletter *Harmful Algae News* and access to IOC databases such as HABDIR (Harmful Algae Bloom Expert Directory): http://www.unesco.org/ioc/infserv/director/habdir.htm http://www.unesco.org/ioc/iochome.htm

United States – National Databases and Resources

Aquatic Nuisance Species Task Force The US Government's Aquatic Nuisance Species (ANS) Taskforce website. http://www.invasivespecies.gov

NBII Invasive Species The database developed in accordance with the 1999 Executive Order 13112 on Invasive Species, as guided by the National Invasive Species Council (NISC) and the National Biological Information Infrastructure (NBII). NBII's National Marine and Estuarine Invasions Database is at: http://www.nbii.gov/invasive/workshops/smith1.html

Non-indigenous Aquatic Species (US Geological Service). This site describes USGS' information resource on nonindigenous aquatic species (NAS). USGS pages with non-indigenous marine species infornmation are at:

- Nonindigenous Tunicate Information
- Nonindigenous Bryozoan Information
- Nonindigenous Sponge Information
- Nonindigenous Coelenterate Information
- Nonindigenous Annelid Information
- Nonindigenous Mollusk Information
- Nonindigenous Crustacean Information
- Nonindigenous Fish Information

Located at the Florida Caribbean Science Center, the site http://nas.nfrcg.gov/ provides a repository for spatially referenced biogeographic accounts of nonindigenous aquatic species in the US. It contains scientific reports, online querying, spatial data sets, regional contact lists and general information, drawing on data provided by research scientists, interagency groups and general public.

Invasive Species Program (US Fish and Wildlife Service; FWS). Invasive aquatic species prevention and control programme of the FWS.

Seagrant Nonindigenous Species (US Sea Grant's website on non-indigenous species)

National Aquatic Nuisance Species Clearinghouse (entry to the US Seagrant Program)

Sea Grant's National Aquatic Nuisance Species Clearinghouse. A website supported at Cornell University that contains a library focusing on aquatic nuisance species.
http://mdsg.umd.edu/NSGO/research/nonindigenous/

Marine Invasions Research Lab (Smithsonian Institute website, with links to the National Ballast Water Information Clearinghouse). The Smithsonian Environmental Research Center (SERC) at Edgewater, MD, continues to collaborate with scientists around the world in developing an international database of researchers and research studies on aquatic species invasions. SERC's Aquatic Invasions Research Directory (AIRD) can be accessed at: http://invasions.si.edu/aird.htm, and its NEMESIS database provides a comprehensive database linked source on aquatic invasive species (http://invasions.si.edu/nemesis/index.html)

Massachusetts Bay Exotic Species (a Massachusetts Institute of Technology website)

The Nature Conservancy - Publications Library – contains TNC's *Alien species invasions of **US** Ecosystems*, plus links to various government and non-government organizations.

United StatesCoast Guard (USCG) Its 'Operating and Environmental Standards' page leads to its ballast water management and aquatic nuisance species resource, plus access to the Environmental Standards section (http://www.uscg.mil/hq/g-m/mso/mso4/)

US Department of Agriculture Information and rsources on quarantine management of deliberate introductions. Regulations and requirements published by USDA's Animal & Plant Health Inspection Service (APHIS) are at: http://www.aphis.usda.gov/ppd/rad/webrepor.html

http://plants.ifas.ufl.edu/database.html University of Florida's APIRS database (Aquatic Plant Information Retrieval System)

Non-native marine species in US estuaries (NOAA/NERR)

United States - Regional and State Database sources:

US Great Lakes Commission: (Introduced aquatic species in the Great Lakes)
http://www.great-lakes.net/envt/exotic/exotic.html The Great Lakes Information Network
Sea Grant - Great Lakes Network (zebra mussels and other introductions in the Great Lakes)

Great Lakes Panel on aquatic nuisance species: http://www.glc.org/projects/ans/anspanel.html
Western Zebra Mussel Task Force Home Page (A USBR web site)

Gulf of Maine Ballast Water and Exotic Species Web Sites
Invasions Research in Chesapeake Bay (SERC)
Virginia Institute of Marine Science exotic species links
National Aquatic Nuisance Species Clearinghouse (New York State Sea Grant)
Chesapeake Bay - SERC's Nonindigenous Species List
The Introduction of Nonindigenous Species to the Chesapeake Bay Via Ballast Water

Florida Sea Grant - exotic species page

Florida Sea Grant - McCann study: http://aquat1.ifas.ufl.edu/mctitle.html
Invasions Research in Florida (SERC)

http://doacs.state.fl.us/~pi/fsca/exoticsinflorida.htm Lists of alien species in Florida and some graphs illustrating the facts of invasions.
Indian River Lagoon Species Inventory
Nonindigenous Species in the Gulf of Mexico
Initial Characterization of Nonindigenous Aquatic Species in the Gulf of Mexico
Gulf of Mexico Program Nonindigenous Species Information and
http://www.gmpo.gov/nonindig.html (non-indigenous species in the Gulf of Mexico).

Western Regional Panel on Aquatic Nuisance Species: http://www.wrp-ans.org/
West Coast Ballast Outreach Project This site is maintained by the Seagrant supported group at Davis (California) contains events, workshops and links on aquatic introductions.
San Francisco Estuary Institute's Biological Invasions Program
San Francisco Estuary Institute - Handbook on Invasive Aquatic and Wetland Plants
Introduced Species In the Sacramento-San Joaquin Delta: Sacramento-San Joaquin Delta Atlas
NOAA's exotic species list for Monterey Bay National Marine Sanctuary (near San Diego)

Marine NIS in Washington State and adjacent waters (Wash Dept. Fish & Wildlife)
http://www.wsg.washington.edu/ Marine bioinvasions - Washington State Sea Grant
Pacific Ballast Water Group and Pacific Northwest Marine Invasive Species Team
Pathways and Management of Marine Nonindigenous Species in the Shared Waters of British Columbia and Washington
Invasions Research in Alaska (SERC)
Nonindigenous Aquatic Nuisance Species (Prince William Sound)

http://www2.bishopmuseum.org/HBS/invert/list_home.htm Checklist of marine invertebrates in the Hawaiian Islands, including introduced species (updated version can be accessed via: http://www2.bishopmuseum.org/HBS/invertguide/index.htm)
http://www.hear.org/AlienSpeciesInHawaii/index.html Data on invertebrate species which are or might be invasive if introduced to Hawaii. Introduced macroalgae to Hawaii:
http://www.botany.hawaii.edu/GradStud/smith/websites/ALIEN-HOME.htm
http://www.botany.hawaii.edu/GradStud/smith/invasive/BROCHURE.htm
http://www.hawaii.edu/reefalgae/invasives/
Hawaiian Islands aquatic species (brackish & fresh water)

American Fisheries Society position on introduced species: http://www.afsifs.vt.edu/afspos.html

Canada

Canadian Coastguard (for ballast water management requirements): www.ccg-gcc.gc.ca (or from Transport Canada (www.tc.gc.ca)

Department of Fisheries and Oceans (DFO) (www.ncr.dfo.ca/index.htm)
DFO - Ballast water and marine invasions (DFO) - Contains summaries of Canadian activities, case histories of introduced species and shipping study reports such as *Exotic phytoplankton from ships´ ballast water - risk of potential spread to mariculture sites on Canada's East Coast*. Aquatic Invaders in the southern Gulf of St. Lawrence (DFO: updated 13 June 2003).

CSA (Canada Shipping Act). This government site describes the various regulations which have been implemented under the Act, including those designed to limit ship-mediated introductions.

CBIN (Canadian Biodiversity Information Network). CBIN is a Canadian website focussing on ballast water. It includes information on commercial ships & shipping, aquatic nuisance species, guidelines and legislation and other references, resources and links.

Europe

CIESM (International Commission for the Scientific Exploration of the Mediterranean Sea) CIESM is headquartered in Monaco and has commenced publishing 'atlas volumes' of marine species introductions in the Mediterranean that can be ordered from its website. This site also contains lists detailing the large number of fish, molluscs and crustaceans introduced to the Mediterranean (see Appendix D). The proceedings of a CIESM workshop on ship-mediated introductions into the Mediterranean and Black Sea regions (held in Istanbul, November 2002) are also available as a downloadable monograph (*Alien marine organisms introduced by ships in the Mediterranean and Black Seas. CIESM Workshop Monographs No.20*, 136 pp). This can be ordered on-line or downloaded in full from http://www.ciesm.org/publications/Istanbul.html (.pdf format). The papers review current knowledge gaps, provide data compilations and analyses (including shipping movement patterns within the region) and offer recommendations for action and research.

BMB-WG NEMO (Baltic Marine Biologists Working Group on Non-indigenous Estuarine and Marine Organisms). This group established an internet inventory in 1997 which was subsequently incorporated into a database maintained by the Klaipeda University's CORPI team in western Lithuania. The Project Co-ordinator is Dr. Sergej Olenin (serg@gmf.ku.lt). The Baltic Sea region contains about one hundred marine and freshwater introductions originating from North America, the Ponto-Caspian region, East Asia and other regions. The Baltic has also been a donor area, exporting several native species to other regions. The goals of the database are to:

- provide a reliable online reference system on aquatic alien species for the Baltic Sea are for environmental managers, researchers, students and general public;
- encourage data exchanges between different geographical regions and update the information on the biology, vectors, spread and impacts Baltic Sea alien species via an online questionnaire which solocits information from research institutions and responsible environmental authorities; and
- eventually serve as a regional node in GISIN (e.g. Ricciardi A, Steiner WWM, Mack RN & D Simberloff, 2000. Toward a Global Information System on Invasive Species. *BioScience 50*, 239-244).

EU Concerted Action (*Testing Monitoring Systems for Risk Assessment of Harmful Introductions by Ships to European Waters*). This website is maintained by Dr S. Gollasch (GoConsulting, Germany; sgollasch@aol.com), and contains materials describing a project involving six European countries (Finland, Germany, Ireland, Lithuania, Sweden, United Kingdom) funded by the European Union MAST-Programme and co-ordinated by Germany. Scientists from Norway, The Netherlands, Croatia, Israel, Italy and Turkey) have also been involved. The main objective was to compare the effectiveness of various methods of sampling ballast water. The EU Concerted Action has led to a continuing program involving ICES WGITMO and ICES/IOC/IMO SGBWS. Members of the Concerted Action group included: Prof. Dr. Harald Rosenthal, Institut für Meereskunde, Düsternbrooker Weg 20, 20146 Kiel, Germany (Project Coordinator); Dr. Stephan Gollasch, Institut für Meereskunde, Düsternbrooker Weg 20, 20146 Kiel, Germany (Co-coordinator); Dr. Ian Laing, CEFAS Conwy Laboratory, Benarth Road, Conwy, North Wales, LL32 8UB, UK; Prof. Dr. Erkki Leppäkoski, ÅBO Akademi University, Dept. of Biology, Bio City, FIN-20520 Turku / Abo, Finland; Dr. Elspeth Macdonald, Marine Laboratory Aberdeen, P.O.Box 101, Victoria Road, Aberdeen AB11 9DB, Scotland, UK; Dr. Dan Minchin, Fisheries Research Centre, Department of the Marine, Abbotstown, Dublin 15, Ireland; Dr. Manfred Nauke, Office of the London Convention 1972, Marine Environment Division International Maritime Organization, 4 Albert Embankment, London, SE1 7SR, UK; Dr. Sergej Olenin, Coastal Research and Planning Institute, Klaipeda University, Manto 84, 5808 Klaipeda, Lithuania; Dr. Sue Utting, CEFAS Conwy Laboratory, Benarth Road, Conwy, North Wales, LL32 8UB, UK; Dr. Matthias Voigt, Environmental Consultant, Kampstr. 7, 24601 Stolpe, Germany; Prof. Dr. Inger Wallentinus, Department of Marine Botany ,University of Göteborg, Carl Skottsberg gata 22 b, 41319 Göteborg, Sweden; Prof. Dr. Inger Wallentinus, Department of Marine Botany ,University of Göteborg, Carl Skottsberg gata 22 b, 41319 Göteborg, Sweden.

Nordic Countries A Danish website providing information on who works with invasive or introduced species in the Nordic countries.

German Shipping Study This site contains a summary of a study on non-indigenous marine species transported to German seaports via international shipping, undertaken by the Institut für Meereskunde, Kiel from 1992 to 1995.

http://www.uni-rostock.de/fakult/manafak/biologie/abt/zoologie/Neozoen.html Information on non-indigenous species in Germany, with a particular focus on invasive species biology and genetics (in German).

UK's Directory of non-native marine species in British waters This directory of introduced Species in Great Britain contains a database of non-native marine species and is maintained by The Joint Nature Conservation Committee of Great Britain.

UK Marine SAC project: http://www.ukmarinesac.org.uk/activities/ports/ph6_3_4.htm

Russia Group on Aquatic Alien Species (GAAS). This website is located at the Russian Academy of Sciences.

Ukraine Global Ballast Water Management Programme: http://www.globallast.od.ua/

India Global Ballast Water Management Programme: http://www.globallastwaterindia.com

Australia

AQIS (Australian Quarantine and Inspection Service) is part of Department of Agriculture, Forestry and Fisheries (DAFF), which has been the lead Australian agency for the management of ballast water and hull fouling issues, including policy development, implementation of a strategic research plan and quarantine operations. Available topics include: - Australian Ballast Water Bulletins, Australian Ballast Water Management Strategy and Ballast Water Guidelines, and publications from the Australian Ballast Water R&D Programme.

NIMPIS (National Introduced Marine Pest Information System) is Australia's national database developed and maintained by CSIRO Marine Research (Hobart, Tasmania) to provide managers, researchers, students and the general public access to up to date information on the distribution, biology, and ecology introduced marine species, and potential control options for those designated as pests. The database includes (a) species already introduced to Australian waters, (b) unwanted species that may be introduced in the future ('Next Pests'), and (c) links to other relevant sites including the *Decision Support System* (DSS) used by AQIS. The data in NIMPIS is held in a format allowing its automatic access by the biological risk assessment module of the DSS, which has been trialled since 2001 as a ballast water management tool for international shipping arrivals (AQIS) and, more recently, for some of Australia's coastal shipping (State of Victoria). NIMPIS information may be cited for publication or used for public education material. The correct citation for the complete system is: Hewitt CL, Martin RB, Sliwa C, McEnnulty FR, Murphy NE, Jones T & S Cooper (Editors), 2002. National Introduced Marine Pest Information System. Web publication (Date of access): http://crimp.marine.csiro.au/nimpis/.

CSIRO Marine Research - Introduced Marine Pests in Australia

Department of Environment & Heritage (DEH) Information on invasive species in Australia

New Zealand - Ministry of Fisheries: www.fish.govt.nz

New Zealand - Biosecurity main page

http://www.niwa.co.nz/ncabb/ (NZ National Centre for Biodiversity & Biosecurity Research)

NZ Cawthron Institute New Zealand's private research institute, specializing in aquaculture, biosecurity, coastal & estuarine ecology, freshwate ecology and analytical laboratory services.

Biosecurity Management in New Zealand Landcare site containing information on the Biosecurity Act and management of pests in New Zealand.

NZ Government - Undaria Campaign Program

Brazil: Global Ballast Water Management Programme: http://www.mma.gov.br/aguadelastro/

Argentina: Prevention & control of invasive bivalves: http://www.way.com.ar/~invasion/index.htm

Web Sources on Prevention and Surveillance of Marine Species Incursions:

NISC Invasive Species: This website is maintained by the National Agricultural Library of the US Department of Agriculture (contact address: invasive@nal.usda.gov). The *Prevention of Invasive Species* (http://www.invasivespecies.gov/toolkit/prevention.shtml) is part of the NISC Manager's Toolkit (http://www.invasivespecies.gov/toolkit/main.shtml).

100th Meridian Initiative: A cooperative effort between state, provincial, and federal agencies to prevent the westward spread of zebra mussels and other aquatic nuisance species in North America: http://www.100thmeridian.org/

Great Lakes Commission, A Model Comprehensive State Management Plan for the Prevention and Control of Nonindigenous Aquatic Nuisance Species as approved by the Great Lakes Panel on Aquatic Nuisance Species, January 1996.

A Prevention Program for the Mediterranean Strain of *Caulerpa taxifolia*

Submitted to the Aquatic Nuisance Species Task Force by Sandra M. Keppner,, U.S. Fish and Wildlife Service, Lower Great Lakes Fishery Resources Office and Russell T. Caplen, Animal and Plant Health Inspection Service, August 1999

Ballast Water Management (US Coast Guard guidelines; see also AQIS and IMO above).

On board treatment of ballast water and application of low-sulphur marine fuel (MARTOB) - http://www.marinetech.ncl.ac.uk/research/martob/

Ballast Water Treatment Bookshop: http://www.watertreatmentbooks.com

Ballast water treatment research: Singapore Environmental Technology Institute: www.eti.org.sg/ballast.pdf

Clearwater Magazine: http://www.nywea.org/311080.html

Discussion Paper on the Screening Process for Intentional Introductions (RTF document) Richard Orr, National Invasive Species Council (NISC), August 2000.

Responses to Questions on the Discussion Paper on the Screening Process (Rich text format): Richard Orr, National Invasive Species Council (NISC), August 2000.

Exotic Policy: An International Joint Commission White Paper on Policies for the Prevention of the Invasion of the Great Lakes by Exotic Organisms: Eric Reeves, July 1999

IUCN Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species Prepared by the Species Survival Commission, Invasive Species Specialist Group (ISSG). Approved February 2000.

Invasive Alien Species - A Toolkit of Best Prevention and Management Practices and Chapter 3 Prevention: from CAB International, on behalf of the Global Invasive Species Programme (GISP), September 2001.

Invasive Species Monitoring Approaches for Volunteer Programs (pdf format). 15th Annual National Conference Enhancing States' Lake Management Programs (April 24 -26, 2002), Chicago, Illinois, Elizabth Herron

Plan for the Prevention and Control of Nonindigenous Aquatic Nuisance Species in the Colorado River Basin. Draft plan for consideration by the Colorado River Fish and Wildlife Council, December 1998.

Prevention : National Institute of Invasive Species Science (NIISS, Colarado State).

Sources on Rapid Response Toolboxes, Control and Chemical Treatment Options

Bax, N.J. and McEnnulty, F.R. (2001). *Rapid response options for managing marine pest incursions. Final Report for NHT/C&CS project*. Available in downloadable sections from:
Section I: Executive summary (http://crimp.marine.csiro.au/reports/TBExecSum.pdf)
Section II*:* (McEnnulty FR, Bax NJ, Schaffelke B & Campbell ML (2000): *A literature review of rapid response options for the control of ABWMAC listed species and related taxa in Australia* (http://crimp.marine.csiro.au/reports/Toolbox.pdf).
Section III: Jones TE, McEnnulty FR, Bax NJ (2001) *The Wed-Based Rapid Response Toolbox* (http://crimp.marine.csiro.au/NIMPIS/controls.htm)

http://www.cawthron.org.nz/Assets/Undaria_full_report.pdf Control and eradication review by the NZ Cawthron Institute, with a focus on *Undaria* Japanese kelp).

http://www.landcare.cri.nz/science/biosecurity/ Management of pests in New Zealand.

California Department of Pesticide Regulation; useful links page: http://www.cdpr.ca.gov/

EXTOXNET InfoBase - provides a variety of information on pesticides: http://ace.ace.orst.edu/info/extoxnet/

University of Nebraska's Pesticide education resources: http://www.ianr.unl.edu/ianr/pat/ephome.htm

Sea Grants National Aquatic Nuisance Species Clearinghouse: http://cce.cornell.edu/seagrant/nansc/SGNIS

Other links to pesticide information sources are available at the US Federal Interagency Committee for the Management of Noxious and Exotic Weeds: http://refuges.fws.gov/NWRSFiles/InternetResources/Pesticide.html

www.nbii.gov/invasives Social marketing in the management of invasive species.

http://massbay.mit.edu/exoticspecies/index.html This marine invasion resource includes descriptions of pathways, prevention and control topics.

http://www.dnr.cornell.edu/bcontrol/ Biological control of non-indigenous species.

Summary of Activities of the National Seastar Task Force in Australia

Managing Ballast Water to Stop the Introduction of Non-Indigenous Species

Pimentel, 2003. *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species.*

Conventions, Laws & Regulations:

International Conventions

- International Legal Instruments with Programs / Activities pertaining to Invasive Species
- Codes of Conduct / Guidelines pertaining toinvasive species
- Declarations and Reports

US Federal Laws & Regulations (NISC website)

- Executive Order 13112 (established National Invasive Species Council)
- Invasive Species Bills - 108th Congress
- Invasive Species Bills - 107th Congress
- Hearings and Testimony
- Federal Acts, Agencies, and Authorities pertaining to Invasive Species
- http://www.anstaskforce.gov/nanpca.htm Details the *Non-indigenous Aquatic Nuisance Prevention and Control Act*, as introduced on November 29, 1990, as amended by the *National Invasive Species Act* of 1996.
- http://thomas.loc.gov/cgi-bin/query/D?c106:1:./temp/c10698Ags1 Details the US *Noxious Weed Coordination and Plant Protection Act*, as introduced April 29, 1999 (Senate bill 910), which regulates the interstate movement of weeds including aquatic plants.

US State Laws & Regulations (NISC website):

- State Specific Laws and Regulations pertaining to Invasive Species
- Washington state Ballast Water Regulations (passed March 6, 2000) - pdf

Legislation, Regulation and Policy for the Prevention and Control of Nonindigenous Aquatic Nuisance Species: Model Guidance for Great lakes Jurisdictions Approved by the Great Lakes Panel on Aquatic Nuisance Species (prepared by the Great Lakes Commission, June 1999).

Sources and publications on Risk Assessment and Risk Management:

Committee on Environment and Natural Resources, National Science and Technology Council. Ecological Risk Assessment in the Federal Government. May 1999. 219 pp.

Commission of the European Communities, Communication on the Precautionary Principle (Brussels 02 February 2000): http://europa.eu.int/comm/environment/docum/20001_en.htm

Research Questions about Introductions: http://ipif.psw.fs.fed.us/introductions.htm

National Research Council, *"Risk Assessment in the Federal Government: Managing the Process,"* National Academy Press, Washington, D.C. 1983.

Norton TW, Bear T & S Dovers, 1996. *Risk and Uncertainty in Environmental Management: Proceedings of the 1995 Australian Academy of Science Fenner Conference on the Environment*. Centre for Resource and Environmental Studies, Australian National University, Canberra.

U.S. Department of Agriculture, Forest Service, Institute of Pacific Islands Forestry, Invasive Species Research Team Jones, Phillip B.C. "Precautionary Principle: Legal Doctrine or Rorschach Ink Blot Test?" ISB News Report. September 2000.

Sources on Aquatic Pathways:

Washington Sea Grant Program: Pathways of Aquatic Introductions: http://www.wsg.washington.edu/outreach/mas/aquaculture/pathways.html

American Fisheries Society: Position on aquatic species introductions: http://www.afsifs.vt.edu/afspos.html

Netherlands' ORTEP Association: Pathways of introduction and the ecological and economic impacts of invasive species: http://www.ortepa.org/pages/ei26.htm

Great Lakes Aquatic Nonindigenous Species List - Mechanisms of Introduction (compiled by the Great Lakes Environmental Research Laboratory of the NOAA National Center for Aquatic Invasive Species Research, with assistance of the University of Michigan's Cooperative Institute for Limnology and Ecosystems Research, updated May 2002): http://www.glerl.noaa.gov/res/Programs/invasive/ansmechofintro052703.html

Miscellaneous sources, articles, invasive marine species pages and publications:

CQD Journal for the Maritime Environment Industry – a not for profit organisation focussing on improving environmental management measures by maritime industries, with a consistent focus on shipping. Example articles include: *Invasive Species- in the ballast water or on the hull?* (http://cqdjournal.com/html/env_5.2.htm)

Invasive Species of Indian Ocean Islands (NBII website)

Marine Biological Invasion References

Marine Invasions and the Preservation of Coastal Diversity

Harmful Algae web page (maintained by the Woods Hole Oceanographic Institution)

Information on the toxic 'ambush' dinoflagellate *Pfiesteria piscicida* (including pictures) can be found at: http://www2.ncsu.edu/unity/lockers/project/aquatic_botany/pfiest.html, and http://www.cdc.gov/nceh/press/1997/970929pf.htm
http://www.epa.gov/OWOW/estuaries/pfiesteria/hilite.html

Caulerpa taxifolia: Laboratoire Evironnement Marin Littoral (LEML), Université de Nice-Sophia Antipolis. Contains photographs, maps, references, etc. Spread of *Caulerpa taxifolia* in the Mediterranean Sea also available on the GIS Posidonie bibliographic database at: http://com.univ-mrs.fr/gisposi/gisposi.htm . For the latest news on the distribution of *Caulerpa taxifolia* in the Mediterranean Sea [in French] choose "*Pour avoir les dernieres nouvelles sur la Caulerpa*" at http://www.com.univ-mrs.fr/basecaul For 2003 updates in California, go to http://www.caulerpa.cjb.net/ (background http://swr.nmfs.noaa.gov/hcd/CAULERPA.htm).

Zebra Mussel (*Dreissena polymorpha*) : http://www.science.wayne.edu/~jram/zmussel.htm

Ascidians - http://nsm.fullerton.edu/~lamberts/ascidian/
European green crab (*Carcinus maenas*): http://www.tidepool.org/derek/greencrab.html
http://www.mov.vic.gov.au/crust/mov1658i.html
http://www.mov.vic.gov.au/crust/mov1658t.html
http://www.mdsg.umd.edu/MDSG/Communications/MarineNotes/Mar-Apr96/

Invasive crayfish in Europe (select "EVENTI") maintained by the University of Firence, Italy.

Zebra mussel links: http://www.science.wayne.edu/~jram/zmlinks.htm and http://www.nfrcg.gov/zebra.mussel/

AN Cohen & JT Carlton (1995): Non-Indigenous Aquatic Species in a United States Estuary: A case Study of the Biological Invasions of the San Francisco Bay and Delta. Report for the United States Fish and Wildlife Service, Washington D.C. and The National Sea grant College Program, Connecticut Sea Grant. The Home Page (http://www.sfei.org/invasions.html) provides further information and links.

Exotic Species Update: Are Ballast Water Regulations Working? (Carlton)

US OTA's (1993) Report on Aquatic Nuisance Species *(Harmful non-indigenous species in the United States,1993)*.It can also be found at http://www.wws.princeton.edu/~ota/index.html by selecting "OTA Publications" (then selecting by date and title)

America's Least Wanted (1998) A report produced by The Nature Conservancy on alien species invasions of US ecosystems, including several marine species.

Aquatic Invasive Species Conference (October 2001): http://www.aquatic-invasive-species-conference.org/

AGENCIES AND ORGANISATIONS:

National Invasive Species Council (NISC) Department of the Interior Office of the Secretary (OS/SIO/NISC) 1849 C Street, N.W. Washington, DC 20240, United States	Courier Address: National Invasive Species Council Office of the Secretary (OS/SIO/NISC) 1201 Eye Street, 5th Floor Washington, DC 20005
Phone: (202) 513-7243 E-mail: invasivespecies@ios.doi.gov	Fax: (202) 371-1751

National Biological Information Infrastructure(NBII)	
U.S. Geological Survey, MS 302 12201 Sunrise Valley Drive Reston, Virginia 20192, United States	Invasive Species Theme Coordinator - Annie Simpson asimpson@usgs.gov
www.nbii.gov;	http://invasivespecies.nbii.gov
Phone: 1-703-648-4281	Fax: 1-703-648-4224

APPENDIX B

Availability and Regulations for the use of Control Chemicals in Marine Environments

(updated and shortened from McEnnulty *et al*, 2000)

The total number of chemicals on the global market is close to 100,000. When responding to a marine invasive species incursion, identification of treatment chemicals for possible use needs to consider internationally and nationally accepted practices. A nation's chemical regulations typically cover a wide range of chemicals including dyes, solvents and plastics, agricultural, industrial and laboratory chemicals, medical and veterinary drugs, paints and cleaning agents and cosmetics. The availability, handling and use of these chemicals are also likely to be influenced by International Agreements as well as internal State, Provincial or City regulations.

INTERNATIONAL AGREEMENTS

There are several intergovernmental bodies which examine chemical safety and provide information-sharing between countries. 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.

Representatives of 95 countries reached an agreement in 1998 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. Convention details are available at the joint FAO/UNEP PIC website.

Concise International Chemical Assessment Documents (CICADS) are publications from the International Programme on Chemical Safety (IPCS), a cooperative program of the World Health Organization (WHO), UNEP and the International Labour Organisation (ILO). These documents provide summaries of the potential effects of chemicals on human health and the environment, and are available from the CICADS website.

NATIONAL REGULATIONS - NEW ZEALAND AND AUSTRALIA EXAMPLES

In New Zealand, the Environmental Risk Management Authority (ERMA) makes decisions on applications to introduce hazardous substances (HS) and new organisms (NO), including genetically modified organisms (GMOs). Details on the approved and unapproved substances and organisms, as recorded by the ERMA since the 1 July 2001 start of the 'Hazardous Substances' part of New Zealand's *HSNO* Act, can be downloaded from:
http://www.ermanz.govt.nz/search/substance1.cfm

Chemical regulation in Australia is generally managed at the national level by the Commonwealth Government of Australia, while the Australian States and Territories have regulations for managing chemicals from their point of sale to their use and disposal. Fields covered include transport, storage, occupational health and safety (OH&S), environmental protection and waste disposal. There are three national schemes most relevant for chemicals potentially suited to the control or eradication of marine NIS:

- National Registration Scheme for Agricultural and Veterinary Chemicals (maintained by Product Safety and Integrity (PSI) section of the Department of Agriculture, Forestry and Fisheries
- Designated Hazardous Substances Database (mostly industrial chemicals at the NOHSC website: http://www.nohsc.gov.au/OHSInformation/Databases/HazardousSubstances/)
- Therapeutic Goods Administration (TGA) for pharmaceuticals and regulation of poisons (http://www.health.gov.au/tga)

Each scheme provides a consistent set of standards to be applied across jurisdictions in the risk management of chemicals. 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. The pharmaceuticals, food additives and contaminants schemes focus on human health.

The potential for a chemical to impact adversely on the environment or public health. the schemes rely on the Commonwealth Department of Environment & Heritage (Aus-DEH) to assess the potential impact of a chemical on Australia's environment, plus the the National Occupational Health and Safety Commission (Aus-NOHSC) to assess worker safety and the Commonwealth Department of Health (DHS) to evaluate potential human health effects.

Australia has established 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 and vegetation effects, whereas the water standards are concerned with protecting the wider environment. 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.

Registered chemicals that may be considered for the control or eradication of marine NIS include those listed in Table 1. Some of these are registered for use in some Australian States or Territories and not others. Some are approved for restricted purposes only.

In recent years many organochlorine pesticides (OCPs) have been deregistered in Australia and other countries, such as Azinophos-ethyl (an organophosphate pesticide), chlordane, dieldrin, DDT, endosulphan, endrin and pentochlorophenol (including its salts e.g. "Santobrite" sodium pentochlorophenate). Lindane and mirex are among the few organochlorine pesticides (OCPs) still registered for limited use in some parts of Australia. The following herbicides and piscicides are probably not registered in Australia: Antimycin, Feneron, gluphosinate, TFM and 2,2-dichloroproionic acid (as the sodium salt, eg. Dalapon in the UK).

Registered agricultural/veterinary chemicals carry approved labels 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 specific purpose/s stated on the label. The label on all agricultural glyphosate products warns their use in or adjacent to waterways (ditches, drains, lakes etc) is precluded unless authorised; with their usage in sensitive aquatic situations allowed only if it can be demonstrated that the selected formulation will not pose a significant risk to the aquatic environment. Penalties apply for misuse of pesticides, with higher penalties for wilful or negligent misuse offences.

Table 1. Registered chemicals that may be considered for the control or eradication of invasive marine species (August 2000)

Active ingredient	No. of listed products	Type of chemical	Comment
2,4-D	93	Herbicide	
Atrazine	40	Selective systematic herbicide	
Carbaryl	62	Insecticides, fungicides, bactericides	Organocarbamate pesticide
Chlorpyrifos	64	Organophosphate insecticides, termiticide	
Coptrol Aquatic Algicide	1	Copper algicide	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
Fluazifo	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 NRA has a permit scheme which provides for situations where it may be necessary to use a registered or unregistered product in an unapproved (off-label) manner. This includes emergencies such as outbreaks of contagious disease or exotic pests for which no registered products exist. Such permits will 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. For example, the Rice Grass Advisory Group obtained a special 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 coastal environments.

Industrial and agricultural/veterinary chemicals are also subject to assessments and controls on importation, manufacture and use which are 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. The MSDSs are available from the manufacturers, vendors, NOHSC and other internet sources. The NOHSC website contains a list of Designated Hazardous Substances, and is the first reference point in Australia for suppliers determining which substances they supply are hazardous, and for appropriate risk and safety information.

A Designated Hazardous Substance means that care must be taken in its handling and use, in accordance with information and advice on its MSDS sheet. Chemicals on this list which might be considered as a possible treatment for a targeted marine invasive species include: acridine, ammonium chloride, ammonia, benzene and related compounds, bromine, calcium hypochlorite, copper(1)chloride, copper oxide, copper sulphate, creosote, chlorine, chloramine, hydrochloric acid, hydrogen peroxide, pentachlorophenol and its alkali salts, phenol and related compounds, potassium permanganate, sodium hypochlorite, sodium azide and tributyltin compounds.

Agricultural and veterinary chemicals are also assessed by the National Drugs and Poisoning Scheduling Committee (NDPSC), and recommended for scheduling within the Standard for Uniform Schedule of Drugs and Poisons (SUSDP) as and where necessary. A large number of chemicals were approved for use before the introduction of NICNAS scheme in 1990. NICNAS has been reviewing some the existing approvals through nomination to the list of *Priority Existing Chemicals* by concerned persons.

Finally, the National Residue Survey (NRS; http://www.nrs.gov.au/residues/aboutnrs.htm) monitors Australian raw food commodities on both domestic and export markets for chemical residues, including agricultural and veterinary chemicals used in food production. This scheme is conducted by the Commonwealth Department of Agriculture, Fisheries and Forestry's Chemicals and Biologicals Branch (http://www.daff.gov.au) and Bureau of Resource Sciences. The NRS surveys provide snapshots of the chemical residue status of agricultural, fishery and aquaculture commodities.

Provincial Regulations

Australia's States and Territories control the use of industrial chemicals mainly through prohibition, application of occupational exposure standards and health surveillance. Most 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, which is based on the UN Recommendations on Transport of Dangerous Goods and is being adopted uniformly by all States and Territories (e.g. HAZCHEM codes on labels).

APPENDIX C

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APPENDIX D

CIESM Atlas of Exotic Species (Volumes 1-3): Checklists of non-native fishes, molluscs and crustaceans in the Mediterranean Sea

The CIESM Atlas of Exotic Species is planned to consist of about five volumes, each written by a group of specialists in their respective field. Individual species pages are designed to stand alone as information sheets with illustrations, diagonistic features, biological information, references and a distribution map for each exotic species. CIESM task force members will continuously review reliable evidence of new or confirmed records for updating and expanding the Atlas. The first volumes to be printed are :

Vol. 1 – Fishes: published in April 2002 – available by order.
Vol. 2 - Crustacean decapods and stomatopods: published October 2002 - available by order.
Vol. 3 – Molluscs: (in preparation).

The Atlas volumes provide a comprehensive survey of recent marine "immigrants" in the Mediterranean, which is undergoing drastic and rapid changes to its biota. The majority of listed species are the so called "Lessepsian" migrants of Indo-Pacific origin, having reached the Mediterranean through the Suez Canal and now significantly contributing to the biodiversity of the Eastern basin. However invaders of other realms - notably from the tropical Atlantic via natural invasion through the Gibraltar straits or from accidental or intentional introductions by man - are becoming frequently recognized as well.

A species must be a relative newcomer to the Mediterranean Sea to be included on the list. This means (a) not having appeared before the 1920's for Lessepsian species (a decade when the Cambridge expedition took place and provided a reliable baseline), or (b) not appearing before 1960 for the others. Species classified as ‘established’ (= have self-maintaining populations) are evidenced by a minimum of two (three for fishes) published records from either different localities or different times. Species identified as ‘Alien’ (=presumed to be not yet established in the basin) are evidenced by only one record (two records for fishes) in the scientific literature. The following tables list the species as recorded in the current three volumes, including their origin (native region/s) and their known or assumed establishment status in the Mediterranean basin.

ATLAS OF EXOTIC MOLLUSCS IN THE MEDITERANNEAN SEA

(http://www.ciesm.org/atlas/appendix3.html)

Check-list of exotic species

Origin : AA = American Atlantic, AS = Arabian Sea, BA = Boreal Atlantic, BPO = Boreal Pacific Ocean, CIRT = Circumtropical, EPO = Eastern Pacific Ocean, IO = Indian Ocean, IP = Indo-Pacific, NPO = Northern Pacific Ocean, PG = Persian Gulf, PO = Pacific Ocean, RS = Red Sea, SA = South Atlantic, SC = Suez Canal, TPO = Tropical Pacific Ocean, TA = Tropical Atlantic, WP = Western Pacific. **Status** : A = Alien, E = Established population.

TAXON	Origin	Status
POLYPLACOPHORA - Chitonidae		
Chiton hululensis	RS, IP	A
GASTROPODA - PROSOBRANCHIA		
Nacellidae		
Cellana rota	RS, IO	E
Haliotidae		
Haliotis pustulata cruenta	RS	A
Fissurellidae		
Diodora ruppellii	IP, RS	E
Neritidae		
Smaragdia souverbiana	IP, RS	E
Nerita sanguinolenta	RS	A
Trochidae		
Trochus erythraeus	RS	E
Pseudominolia nedyma	RS, IO	E
Cerithiidae		
Cerithium nesioticum	RS, IP	A
Cerithium nodulosum	RS, IO	A
Cerithium scabridum	RS, IO	E
Rhinoclavis kochi	IP, RS	E
Clypeomorus bifasciatus	RS, IP	A
Planaxidae		
Angiola punctostriata	RS, IP	A
Planaxis savignyi	RS	A
Litiopidae		
Alaba punctostriata	IP	E
Obtortionidae		
Finella pupoides	IP	E
Clathrofenella ferruginea	IP, RS	E
Dialidae		
Diala varia	IP, RS	E
Cerithiopsidae		
Cerithiopsis pulvis	RS	E
Cerithiopsis tenthrenois	IO	E
Triphoridae		
Metaxia bacillum	RS	E
Rissoidae		
Alvania dorbignyi	RS	E
Woorwindia tiberiana	RS	A
Rissoina bertholleti	RS, IO	E
Rissoina spirata	IP	A
Strombidae		
Strombus persicus	PG, AS	E
Hipponicidae		
Sabia conica	RS, IP	A
Calyptraeidae		
Crepidula aculeata	AA	E
Crepidula fornicata	AA	E
Cypraeidae		
Erosaria turdus	RS, IO	A

Purpuradusta gracilis notata *Palmadusta lentiginosa lentiginosa*	IO, RS IO, PG	E A
Naticidae *Natica gualteriana*	RS, IP	E
Epitoniidae *Cycloscala hyalina*	RS, IP	A
Eulimidae *Sticteulima lentiginosa*	IP	A
Muricidae *Ergalatax obscura* *Thais lacerus* *Rapana venosa* *Rapana rapiformis* *Murex forskoehlii*	RS, AS IO, PG PO RS, IP RS, PG	E E E A E
Vasidae *Vasum turbinellus*	RS, IP	A
Nassariidae *Nassarius arcularius plicatus*	RS, IO	A
Fasciolariidae *Fusinus marmoratus*	RS	E
Columbellidae *Anachis savignyi* *Anachis selasphora*	RS IO, RS	E E
Costellariidae *Pusia depexa*	RS, IO	A
Conidae *Conus fumigatus*	RS	A
GASTROPODA - HETEROBRANCHIA **Anisocyclidae** *Murchisonella columna*	IP	A
Pyramidellidae *Chrysallida fischeri* *Chrysallida maiae* *Chrysallida pirintella* *Adelactaeon fulvus* *Adelactaeon amoenus* *Styloptygma beatrix* *Cingulina isseli* *Turbonilla edgarii* *Syrnola fasciata* *Syrnola cinctella* *Odostomia lorioli* *Oscilla jocosa* *Iolaea neofelixoides*	RS RS RS IP IP PG RS IP IP IP, RS RS RS, PG PO	E E E E E E E E E A A A A
GASTROPODA - OPISTHOBRANCHIA **Cylichnidae** *Acteocina mucronata* *Cylichnina girardi*	RS IP	E E
Retusidae *Pyrunculus fourierii*	IP, RS	E
Bullidae *Bulla ampulla*	IP	E
Haminoeidae		

Haminoea callidegenita	BPO, AA	E
Aglajidae *Chelidonura fulvipunctata*	IP	E
Aplysiidae *Bursatella leachi*	CIRT	E
Pleurobranchidae *Pleurobranchus forskali*	RS	A
Polyceridae *Polycerella emertoni* *Polycera hedgpethi*	TA BPO	E A
Polyceridae / Triophidae *Plocamopherus ocellatus*	RS	A
Chromodorididae *Hypselodoris infucata* *Chromodoris quadricolor*	IP, RS RS	E A
Dendrodorididae *Dendrodoris fumata*	RS, IP	A
Tethyidae *Melibe fimbriata*	IO, PO	E
Tergipedidae *Cuthona perca*	PO	A
Flabellinidae *Flabellina rubrolineata*	IP, RS	A
Glaucidae *Caloria indica*	IP	A
Aeolidioidea *Aeolidiella indica*	CIRT	A
GASTROPODA - DIVASIBRANCHIA **Siphonariidae** *Siphonaria kurracheensis*	IP	E
BIVALVIA - PTEROMORPHIA **Arcidae** *Acar plicata* *Anadara demiri* *Anadara inaequivalvis* *Anadara natalensis*	IP, RS IO IP IO, RS	A E E E
Glycymerididae *Glycymeris arabicus*	IO, RS	A
Limopsidae *Limopsis multistriata*	IP, RS	A
Mytilidae *Musculista perfragilis* *Musculista senhousia* *Modiolus auriculatus* *Xenostrobus securis* *Brachidontes pharaonis*	IP, RS PO, RS IO, RS TPO IO, RS	E E A E E
Ostreidae *Crassostrea gigas* *Saccostrea cucullata*	BPO CIRT	E E
Pteriidae *Pinctada margaritifera* *Pinctada radiata*	IP, RS IP, RS	E E

Malleidae *Malleus regulus*	IP, RS	E
Pectinidae *Chlamys lischkei*	AA	A
Spondylidae *Spondylus spinosus* *Spondylus groschi*	IP, RS IO, RS	E A
BIVALVIA - HETERODONTA **Psammobiidae** *Hiatula ruppelliana*	RS	E
Lucinidae *Divalinga arabica*	RS, AS	E
Trapeziidae *Trapezium oblongum*	IP, RS	A
Chamidae *Chama pacifica* *Pseudochama corbieri*	IP, RS RS	E A
Cardiidae *Fulvia australis* *Fulvia fragilis*	IP, RS IO, RS	E E
Tellinidae *Tellina valtonis* *Psammotreta praerupta*	IO, RS IP, RS	A A
Mactridae *Mactra olorina*	RS	E
Mesodesmatidae *Atactodea glabrata*	IP, RS	A
Veneridae *Gafrarium pectinatum* *Circenita callipyga* *Clementia papyracea* *Paphia textile* *Mercenaria mercenaria* *Tapes philippinarum* *Antigona lamellaris* *Dosinia erythraea*	IP, RS IO, RS IP, RS IP, RS AA PO IP, RS RS, WP	E A E E E E A A
Petricolidae *Petricola pholadiformis*	AA	A
Myidae *Sphenia rueppelli* *Mya arenaria*	RS BA	A E
Gastrochaenidae *Gastrochaena cymbium*	IP, RS	E
BIVALVIA - ANOMALODESMATA **Laternulidae** *Laternula anatina*	IP, RS	E

ATLAS OF EXOTIC CRUSTACEANS IN THE MEDITERRANEAN

(http://www.ciesm.org/atlas/appendix2.html)

Check-list of introduced crustaceans detailed in CIESM Atlas (last updated September 2003)

Origin : **AA** = American Atlantic, **BA** = Boreal Atlantic, **TA** = Tropical Atlantic, **EP** = Eastern Pacific, **IP** = Indo-Pacific, **WP** = Western Pacific. **Status** : **A** = Alien, **E** = Established.

Taxon	Origin	Status
DECAPODA, DECAPOD CRUSTACEANS		
Penaeidae (penaeid prawns)		
Marsupenaeus japonicus	IP	E
Melicertus hathor	IP	E
Metapenaeopsis aegyptia	IP	E
Metapenaeopsis mogiensis consobrina	IP	E
Metapenaeus monoceros	IP	E
Metapenaeus stebbingi	IP	E
Penaeus semisulcatus	IP	E
Trachysalambria palaestinensis	IP	E
Solenoceridae (solenocerid prawns)		
Solenocera crassicornis	IP	A
Luciferidae (luciferid shrimps)		
Lucifer hanseni	IP	A
Pasiphaeidae (pasiphaeid shrimps)		
Leptochela aculeocaudata	IP	A
Leptochela pugnax	IP	E
Palaemonidae (rock shrimps)		
Palaemonella rotumana	IP	E
Periclimenes calmani	IP	A
Alpheidae (snapping shrimps)		
Alpheus audouini	IP	E
Alpheus inopinatus	IP	E
Alpheus migrans	IP	E
Alpheus rapacida	IP	E
Hippolytidae (sea grass shrimps)		
Merhippolyte ancistrota	TA	A
Ogyrididae (ogyridid shrimps)		
Ogyrides mjoebergi	IP	E
Processidae (processid shrimps)		
Processa macrodactyla	TA	A
Palinuridae (spiny lobsters)		
Panulirus ornatus	IP	A
Scyllaridae (slipper lobsters)		
Scyllarus caparti	TA	A
Scyllarus posteli	TA	A
Dromiidae (sponge crabs)		
Dromia spinirostris	TA	A
Raninidae (frog crabs)		
Notopus dorsipes	IP	A
Calappidae (box crabs)		
Calappa pelii	TA	E
Cryptosoma cristatum	TA	A
Leucosiidae (pebble crabs)	IP	E
Ixa monodi	IP	E

Leucosia signata *Myra subgranulata*	IP	E
Matutidae (matutine crabs) *Ashtoret lunaris*	IP	A
Majidae (spider crabs) *Herbstia nitida* *Hyastenus hilgendorfi* *Libinia dubia* *Menaethius monoceros* *Micippa thalia*	TA IP AA IP IP	E E E A E
Portunidae (swimming crabs) *Callinectes danae* *Callinectes sapidus* *Charybdis helleri* *Charybdis longicollis* *Portunus pelagicus* *Thalamita gloriensis* *Thalamita poissonii* *Carupa tenuipes*	AA AA IP IP IP IP IP IP	A E E E E E E A
Panopeidae (panopeid stone crabs) *Dyspanopeus sayi* *Rhithropanopeus harrisii*	AA AA	E E
Pilumnidae (bristle crabs) *Halimede tyche* *Heteropanope laevis* *Pilumnopeus vauquelini* *Pilumnus hirsutus*	IP IP IP IP	A E E A
Xanthidae (xanthid stone crabs) *Atergatis roseus*	IP	E
Dairidae *Daira perlata*	IP	A
Eriphiidae *Sphaerozius nitidus*	IP	A
Goneplacidae *Eucrate crenata*	IP	E
Varunidae *Eriocheir sinensis* *Hemigrapsus sanguineus*	BA,WP IP	A A
Grapsidae (rock crabs) *Percnon gibbesi* *Plagusia squamosa*	AA,TA,EP IP	E A
Ocypodidae (ocypodid crabs) *Macrophthalmus graeffei*	IP	A
STOMATOPODA, MANTIS SHRIMPS **Squillidae** *Erugosquilla massavensis*	IP	E

ATLAS OF EXOTIC FISHES IN THE MEDITERANNEAN

(http://www.ciesm.org/atlas/appendix1.html)

Check-list of introduced fish species

Origin : **BA** = Boreal Atlantic, **IP** = Indo-Pacific, **TA** = Tropical Atlantic.
Status : **A** = Alien, **E** = Established.

Taxon	Origin	Status
CARCHARHINIDAE (requiem sharks)		
Carcharhinus altimus	TA	E
Carcharhinus falciformis	TA	E
Galeocerdo cuvier	TA	A
Rhizoprionodon acutus	TA	A
SPHYRNIDAE (hammerhead sharks)		
Sphyrna mokarran	TA	A
DASYATIDAE (stingrays)		
Himantura uarnak	IP	E
CLUPEIDAE (herrings & sardines)		
Dussumieria elopsoides	IP	E
Etrumeus teres	IP	E
Herklotsichthys punctatus	IP	E
Spratelloides delicatulus	IP	A
MURAENIDAE (moray eels)		
Enchelycore anatina	TA	A
CONGRIDAE (conger eels)		
Rhynchoconger trewavasae	IP	A
MURAENESOCIDAE (daggertooth pike-conger eels)		
Muraenesox cinereus	IP	A
OPHICHTHIDAE (snake eels & worm eels)		
Pisodonophis semicinctus	TA	E
HALOSAURIDAE (halosaurus)		
Halosaurus ovenii	TA	A
ARIIDAE (sea catfishes)		
Arius parkii	TA	A
SYNODONTIDAE (lizardfishes)		
Saurida undosquamis	IP	E
CHAUNACIDAE (seatoads)		
Chaunax suttkusi	TA	A
EXOCOETIDAE (flying fishes)		
Parexocoetus mento	IP	E
BELONIDAE (needlefishes)		
Tylosurus choram	IP	A
HEMIRAMPHIDAE (halfbeaks)		
Hemiramphus far	IP	E
Hyporhamphus affinis	IP	A
FISTULARIDAE (cornetfishes)		
Fistularia commersonii	IP	E
Fistularia petimba	TA	A
SYNGNATHIDAE (pipefishes & seahorses)		
Syngnathus rostellatus	BA	E
ATHERINIDAE (silversides)		
Atherinomorus lacunosus	IP	E
TRACHICHTHYIDAE (slimeheads)	TA	A

Gephyroberyx darwini		
BERYCIDAE (alfonsinos) *Beryx splendens*	TA	A
HOLOCENTRIDAE (soldierfishes or squirrelfishes) *Sargocentron rubrum*	IP	E
SCORPAENIDAE (scorpionfishes) *Pterois miles* *Scorpaena stephanica* *Trachyscorpia cristulata echinata*	IP TA TA	A A E
PLATYCEPHALIDAE (flatheads) *Papilloculiceps longiceps* *Platycephalus indicus* *Sorsogona prionota*	IP IP IP	A E A
SERRANIDAE (groupers) *Epinephelus coioides* *Epinephelus malabaricus*	IP IP	E E
TERAPONIDAE (terapons) *Pelates quadrilineatus* *Terapon puta*	IP IP	E E
APOGONIDAE (cardinalfishes) *Apogon nigripinnis*	IP	E
ACROPOMATIDAE (acropomatids) *Synagrops japonicus*	IP	A
SILLAGINIDAE (sillagos) *Sillago sihama*	IP	E
RACHYCENTRIDAE (cobia) *Rachycentron canadum*	IP	A
CARANGIDAE (jacks, scads & runners) *Alepes djedaba* *Seriola fasciata* *Seriola carpenteri*	IP TA TA	E E E
LEIOGNATHIDAE (ponyfishes) *Leiognathus klunzingeri*	IP	E
LUTJANIDAE (snappers) *Lutjanus argentimaculatus*	IP	A
MULLIDAE (goatfishes or red mullets) *Pseudupeneus prayensis* *Upeneus moluccensis* *Upeneus pori*	TA IP IP	A E E
HAEMULIDAE (grunts) *Pomadasys stridens*	IP	E
SPARIDAE (seabreams or porgies) *Crenidens crenidens* *Diplodus bellottii* *Pagellus bellottii* *Rhabdosargus haffara*	IP TA TA IP	E E E E
PEMPHERIDAE (sweepers) *Pempheris vanicolensis*	IP	E
POMACENTRIDAE (damselfishes) *Abudefduf vaigiensis*	IP	A
MUGILIDAE (grey mullets) *Liza carinata* *Mugil soiuy*	IP IP	E E
SPHYRAENIDAE (barracudas)	IP	E

Sphyraena chrysotaenia *Sphyraena flavicauda*	IP	A
LABRIDAE (wrasses) *Centrolabrus exoletus* *Pteragogus pelycus*	BA IP	A E
PINGUIPEDIDAE (sand perches) *Pinguipes brasilianus*	TA	A
BLENNIDAE (blennies) *Petroscirtes ancylodon*	IP	A
GOBIIDAE (gobies) *Coryogalops ochetica* *Oxyurichthys petersi* *Silhouetta aegyptia*	IP IP IP	A E E
AMMODYTIDAE (sand lances) *Gymnammodytes semisquamatus*	BA	E
CALLIONYMIDAE (dragonets) *Callionymus filamentosus*	IP	E
SIGANIDAE (rabbitfishes) *Siganus luridus* *Siganus rivulatus*	IP IP	E E
SCOMBRIDAE (tunas & mackerels) *Rastrelliger kanagurta* *Scomberomorus commerson*	IP IP	A E
ISTIOPHORIDAE (marlins) *Makaira indica*	IP	A
NOMEIDAE (drift fishes) *Psenes pellucidus*	TA	E
ACANTHURIDAE (surgeonfishes) *Acanthurus monroviae*	TA	A
SOLEIDAE (soles) *Microchirus (Zevaia) hexophthalmus* *Solea senegalensis* *Synaptura lusitanica*	TA TA TA	E E E
CYNOGLOSSIDAE (tonguesoles) *Cynoglossus sinusarabici*	IP	E
MONACANTHIDAE (filefishes) *Stephanolepis diaspros*	IP	E
OSTRACIIDAE (boxfishes or trunkfishes) *Tetrosomus gibbosus*	IP	E
TETRAODONTIDAE (pufferfishes) *Lagocephalus spadiceus* *Lagocephalus suezensis* *Sphoeroides pachygaster* *Torquigener flavimaculosus*	IP IP TA IP	E E E A
DIODONTIDAE (porcupinefishes) *Chilomycterus spilostylus* *Diodon hystrix*	IP TA	A A

APPENDIX E

STATE GOVERNMENT OF NEW SOUTH WALES (AUSTRALIA)

Fish Stocking Draft Fishery Management Strategy and Environmental Impact Statement

Fish stocking is undertaken in many water storage impoundments and rivers throughout the State at a rate of around 7 million fish per annum, and representing the main native angling species (golden perch, silver perch, Murray cod and Australian bass), plus non-native species including Atlantic salmon, brook trout, brown trout, and rainbow trout.

Over the past 18 months, NSW Fisheries and a range of key stakeholders have been developing a draft Fish Stocking Fishery Management Strategy and Environmental Impact Statement (http://www.fisheries.nsw.gov.au/com/fw-fms/fw-fms-eis-pdf.htm) to ensure the activity is conducted in an ecologically sustainable manner. Future fish stocking events conducted in NSW freshwater areas will be carried out under this management strategy. The draft management strategy for fish stocking contains all the proposed rules for management of the activity, objectives for the activity, a description of the way the activity operates, and provides the management framework for at least the next five years. It also outlines a program for monitoring the environmental, social and economic performance of the fishery, establishes trigger points for the review of the strategy, and requires regular reporting on performance in order to ensure that the strategy meets its goals.

An environmental impact statement (EIS) has been prepared which examines the environmental impacts and risks of the existing stocking program and the estimated changes to those impacts and risks if the draft management strategy was implemented. The EIS assesses the impact of the activity on the biophysical, economic and social environments. The draft management strategy seeks to improve the ongoing management of freshwater fish stocking by incorporating:

- comprehensive assessment arrangements to minimise or eliminate impacts of stocking on the environment, including interactions between stocked species and threatened species
- improvements to hatchery production and fish quality through a quality assurance program
- an accreditation scheme for hatcheries involved in the activity
- improved understanding and use of genetic material in fish breeding programs
- improved broodstock collection techniques, husbandry and management
- greater involvement in the activity by Aboriginal people and other stakeholders
- better information management, verification and reporting procedures
- improved performance monitoring and compliance
- improved education and public awareness.

Fish stocking is recognised for its importance to the community in terms of quality recreational fishing, conservation outcomes, employment, and subsequent economic benefits that have grown in response to the activity taking place over many years. The Fish Stocking EIS is on public exhibition from 7th November 2003 to 19 December 2003. Any person may make a submission on the EIS during this period.

APPENDIX F

IMO BALLAST WATER REPORTING FORM AND INSTRUCTIONS

BALLAST WATER REPORTING FORM

(To be provided to the Port State Authority upon request)

1. SHIP INFORMATION			**2. BALLAST WATER**
Ship's Name:	Type:	IMO Number:	Specify Units: M^3, MT, LT, ST
Owner:	Gross Tonnage:	Call Sign:	Total Ballast Water on Board:
Flag:	Arrival Date:	Agent:	
Last Port and Country:		Arrival Port:	Total Ballast Water Capacity:
Next Port and Country:			

3. BALLAST WATER TANKS Ballast Water Management Plan on board? YES NO Management Plan Implemented? YES NO

Total number of ballast tanks on board: ________________ No. of tanks in ballast: ________________ IF NONE IN BALLAST GO TO No. 5.

No. of tanks exchanged: ________________ No. of tanks not exchanged: ________________

4. BALLAST WATER HISTORY: RECORD ALL TANKS THAT WILL BE DEBALLASTED IN PORT STATE OF ARRIVAL; IF NONE GO TO No. 5.

Tanks/ Holds (List multiple sources per tank separately)	**BALLAST WATER SOURCE**				**BALLAST WATER EXCHANGE** Circle one: Empty/Refill or Flow Through					**BALLAST WATER DISCHARGE**			
	DATE DDMMYY	Port or Lat/Long	Volume (units)	Temp (units)	DATE DDMMYY	Endpoint Lat/Long.	Volume (units)	% Exch.	Sea Hgt. (m)	DATE DDMMYY	Port or Lat/Long	Volume (units)	Salinity (units)

Ballast Water Tank Codes: Forepeak = FP, Aftpeak = AP; Double Bottom = DB; Wing = WT; Topside = TS; Cargo Hold = CH; Other = O

IF EXCHANGES WERE NOT CONDUCTED, STATE OTHER CONTROL ACTION(S) TAKEN:____

IF NONE STATE REASON WHY NOT:____

5: IMO BALLAST WATER GUIDELINES ON BOARD (RES. A.868(20))? YES NO

RESPONSIBLE OFFICER'S NAME AND TITLE (PRINTED) AND SIGNATURE: ____

GUIDELINES FOR COMPLETING THE BALLAST WATER REPORTING FORM

SECTION 1: SHIP INFORMATION

Ship's Name: Print the name of the ship. **Owner**: The registered owners or operators of the ship. **Flag**: Country of the port of registry.
Last Port and Country: Last port and country at which the ship called before arrival in the current port - no abbreviations, please.
Next Port and Country: Next port and country at which the ship will call, upon departure from the current port - no abbreviations, please.
Type: List specific ship type, write out or use the following abbreviations:
bulk(bc); roro (rr); container (cs); tanker(ts); passenger (pa); oil/bulk ore (ob); general cargo (gc). Write out any additional ship types. **GT**: Gross tonnage.
Arrival Date: Arrival date at current port. Please use the European date format (DDMMYY)
IMO Number: Identification Number of the ship used by the International Maritime Organization. **Call Sign**: Official call sign.
Agent: Agent used for this voyage. **Arrival Port**: This is the current port. No abbreviations, please.

SECTION 2: BALLAST WATER

(Note: Segregated ballast water = clean, non-oily ballast)
Total ballast water on board: Total segregated ballast water upon arrival at current port - with units.
Total ballast water capacity: Total volume of all ballastable tanks or holds - with units.

SECTION 3: BALLAST WATER TANKS

Count all tanks and holds separately (e.g. port and starboard tanks should be counted separately)
Total No. of Tanks on board: Count all tanks and holds that can carry segregated ballast water.
Ballast Water Management Plan on board?: Do you have a ballast water management plan, specific to your ship, onboard? Circle Yes or No.
Management Plan Implemented?: Do you follow the above plan? Circle Yes or No.
No. of Tanks in Ballast: Number of segregated ballast water tanks and holds with ballast at the start of the voyage to the current port. If you have no ballast water on board, go to section 5.
No. of Tanks Exchanged: This refers only to tanks and holds with ballast at the start of the voyage to the current port.
No. of Tanks Not Exchanged: This refers only to tanks and holds with ballast at the start of the voyage to the current port.

SECTION 4: BALLAST WATER HISTORY

BW Source: Please list all tanks and holds that you have discharged or plan to discharge in this port. Carefully write out, or use codes listed below the table. Follow each tank across the page, listing all source(s), exchange events, and/or discharge events separately. If the ballast water history is identical (i.e. the same source, exchange and discharge dates and locations), sets of tanks can be combined (example: wing tank 1 with wing tank 2, both water from Belgium, exchanged 02.11.97, mid ocean). Please use an additional page if you need, being careful to include the arrival date, ship's name and IMO number at the top.
Date: Date of ballast water uptake. Use European format (DDMMYY).
Port or Latitude/Longitude: Location of ballast water uptake.
Volume: Volume of ballast water uptake, with units.
Temperature: Water temperature at time of ballast water uptake, in degrees centigrade (Celsius).
BW Exchange: Indicate Exchange Method: Circle empty/refill or flow through.
Date: Date of ballast water exchange. Use European format (DDMMYY).
Endpoint or Latitude/Longitude: Location of ballast water exchange. If it occurred over an extended distance, list the end point latitude and longitude.
Volume: Volume of ballast water exchanged, with units.
Percentage exchanged: Percentage of ballast water exchanged. Calculate this by dividing the number of units of water exchanged by the original volume of ballast water in the tank. If necessary, estimate this based on pump rate. (Note: For effective flow-through exchange this value should be at least 300%).