Introduced marine pests- how they get here, how do we get rid of them, and how do we know they are really introduced?

Pat Hutchings

The Australian Museum, 6 College Street, Sydney, NSW 2010

path@austmus.gov.au

ABSTRACT

Numerous marine introductions into Australian waters have occurred and will continue to occur. The mechanisms by which they occurred and the difficulties of eradication once they have become established are discussed. Introduced species are often categorised as being either a pest or cryptogenic and the criteria used to distinguish between these categories is discussed, although they may not be mutually exclusive. The main concern is that, for most species, we lack information as to the impact which they are having on native species and their associated marine communities. Finally, the difficulty in determining the native range of a species and the taxonomic difficulties of deciding if a species represents a new invasion, or just a natural range extension is commented on.

Key words: marine introductions, pest species, cryptogenic species, taxonomic uncertainties, native ranges.

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Introduction

A large number of introduced marine species have been documented as occurring in Australian waters, many of these are benign or appear to be, but some have become major pests (www.marine.csiro.au/crimp/nimpis/). In this paper a summary of the ways in which such species have been introduced into Australian waters is given together with methods of eradication and minimising their introduction. The problems of deciding if a species is actually introduced or not is also discussed.

Definition of a pest

Worldwide species are being introduced into habitats outside of their natural ranges in all environments. For most countries, the number of introductions is within the range of 10^2- 10^4 species (Lodge 1993). It is suggested that this is an underestimate as the introductions of large number of species go undetected. Some of these invasions become serious pests causing major ecological impacts and such species are widely accepted as one of the leading direct causes of biodiversity loss (Mack *et al.* 2000), although another plausible alternative hypothesis is that exotic dominance could be the indirect consequence of habitat modification driving native species loss (Didham *et al.* 2005). Attempts to experimentally demonstrate the impact of invasive species are limited and almost entirely restricted to terrestrial environments and mainly consider plants (Farnsworth 2004, MacDougall and Turkington 2005). Didham *et al.* (2005) suggest that while such studies are useful they highlight the need for greater awareness of the interactions among multiple drivers of species loss and greater scientific rigour in assessing the mechanistic causes of population decline.

In Australia a number of marine introductions have been classified as pests (Hayes *et al.* 2005) based on a variety of categories (see Table 2 in Hayes *et al.* 2005) including human health, economic and environmental concerns. Dickman (2006) further discusses the definition of pests and how some pests have almost become acceptable in the terrestrial environment, and even in the marine environment there are such examples (Pacific oyster *Crassostrea gigas)*.

Methods of Introduction

Deliberate

Species have been introduced into Australian waters by a variety of mechanisms including species being deliberately introduced for aquaculture, and which have since become pests. One of the best examples of a species introduced for aquaculture, is the Pacific oyster *Crassostrea gigas* which was introduced into Tasmania in the late 1940s and early 1950s and has spread along the east Australian coast (Pollard and Hutchings 1990b), and is competing with the native Sydney Rock oyster *Saccostrea glomerate* which is widely regarded as the superior species in terms of taste, but not shelf life which has financial implications for the marketability of both species of oysters. Pacific oysters breed early in the year and their spat settles and occupies suitable settlement sites for the Sydney Rock oyster which spawns later, and their settlement is inhibited by the presence of recently settled Pacific oysters (Nell *et al.* 2000).

Accidental

Introduced marine species have been arriving in Australia since the continent was formed, being transported via floating pieces of wood or pieces of pumice which are often home to goose barnacles and amphinomid polychaetes (pers. observ.).

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Other species have been introduced via floating algae, or logs, especially encrusting species such as the spirorbid polychaetes, which have either short or no pelagic stages. Spread of these species would be slow or impossible without transport by flotsam (including stones in the holdfast of buoyant algae) and shipping either by hull fouling or in ballast tanks (Knight-Jones and Knight-Jones 1979, and reference therein). As a result, spirorbid species have been spread around the world with many Pacific species common in the East Atlantic as an example (Knight-Jones and Knight-Jones 1980).

Human aided introductions

More recently, another area of concern is floating oil rigs, which have been towed to a port awaiting decommission, or those which need to be moved to a new drilling location. These platforms are effectively acting as floating, hard substrate habitats, which are then relocated to a new environment with all the flora and fauna attached to them (Coles and Eldridge 2002; Hutchings *et al.* 2002). Similarly, ships waiting to be towed to the breakers yard, often in foreign countries, or waiting for a new owner who may then move to a distant location before cleaning the hulls, are another potential source of marine introductions, although this has been barely documented.

Additionally, introduced species may carry diseases or parasites, which have the potential to infect closely related species. The presence of the bacterial disease *Aeromonas salmonicida* "Goldfish ulcer disease" on farmed Tasmanian Salmon has been documented by Carson and Handlinger (2006). Introduced carp are thought to have been the source of the parasitic isopod *Lernaea cyprinacea* which can potentially parasitise the native Silver Perch *Bidyanus bidyanus* and have serious consequences for this endangered species (Langdon 1989). Such introductions have the potential to infect estuarine species or species which migrate between marine and freshwater environments.

Our knowledge of marine parasitic pests is limited and almost restricted to commercially important species. Certainly, boring mud worms (*Polydora* spp., and *Pseudopolydora* spp., F. Spionidae: Polychaeta) which infest shells of oysters, have been transported, together with their hosts, all around the world. Currently CSIRO's list of Australian introduced pest and cryptogenic species (Hayes *et al.* 2004) includes such species. However, their real status is difficult to assess, because oyster stocks are regularly moved together with their mud worms, and these movements are rarely documented. In addition, the genus contains many poorly-described species, and probably undescribed species, so determining the true origins of these species may never occur.

As well as free living organisms and associated pests being relocated around the world, bacteria and viruses have also been implicated. A cholera outbreak in Central America was attributed to infected ballast water being discharged into a harbour and taken up by shellfish which was then eaten by humans (Thomson *et al.* 2003). Such infections are feasible if ballast water is taken up in polluted harbours where sewage treatment is limited or non existent as occurs in some ports in south east Asia and Pacific Islands.

Certainly, rates of introductions have increased since the time of European colonisation and the development of regular shipping services. Initially, introductions occurred via hull fouling organisms which were either dislodged accidentally or on purpose from the hull of the ship, or which spawned while in Australian waters and then their larvae survived and developed adult breeding populations. Pollard and Hutchings (1990a, b) documented a large number of such introductions into Australian waters which have occurred over the past two centuries. Many of these are known only from ports although some have spread away from their initial port of inoculation (Bell *et al.* 1987). Species were only listed in cases where voucher material had been lodged in a museum and their identification verified.

The Ballast water issue- commercial shipping

With the advent of bulk carriers in the 1970s, and with Australia being an exporter of bulk materials such as coal and iron ore, specialised ships for carrying one particular type of cargo began to arrive at Australian ports (Kerr 1994). Australia has over 50 international ports, plus many more domestic ports which are distributed all around the country. These bulk carriers arrive full of ballast water, which has been taken on board at an overseas port. It is gradually discharged into an Australian port as the cargo is taken on board in order to maintain the stability of the ship (Hutchings 1993). Not until studies were carried out in the late 1970s and early 1980s, was it shown that ballast water may contain a range of animals and plants, primarily dinoflagellates, and that some of these can survive the physical process of being pumped out of the ship into the surrounding water. This was true even for ships which had been at sea for several weeks, including those from the northern hemisphere, which had crossed the equator. This indicated that the ballast water organisms had survived considerable temperature fluctuations and dark conditions (Williams *et al.* 1988; AMBS 1997). Some of the organisms, typically juvenile stages, were identified as species which have formed viable populations, and some of these have become pests. In other cases, the resting stages of dinoflagellates were incubated in the laboratory from those found in the ballast water tanks indicating they were viable (Hallegraeff and Bolch 1992). Such studies raised the profile of marine introductions, and complementary studies, carried out elsewhere in the world (Carlton 1985, 1887), ensured that this issue became one of international concern. One of the best studied areas, San Francisco Bay USA, has been shown to contain 200 introduced species as well as an additional 125 species whose origins are unknown (Carlton 1996). It has been estimated that between 2-3 billion tonnes of ballast water are transported annually worldwide (Hallegraaeff and Gollasch 2006).

Ballast water versus hull fouling introductions

During the 1980s and 1990s ballast water introductions were the main concern of Australian Quarantine Inspection Service (AQIS), but increasingly it is being recognised that in addition, hull fouling is important

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in transporting exotic marine organisms, on both commercial and recreational boats. Keeping hulls clean is important for commercial shipping for reducing fuel costs and maintaining speeds. In New Zealand protocols are being established using underwater video cameras to check the state of ships hulls and recently AQIS has let a contract to see if this protocol could be extended to cruising yachts in Australia (Hutchings pers. comm.). The owners of such boats may have far fewer incentives to keep their hulls clean and with various restrictions on the use of anti fouling paints they may inadvertently be major carriers of hull fouling. Currently AQIS officers can instruct the owners of such vessels to take their boats out of the water and be cleaned if excessive hull fouling is obvious, but this can only be enforced for yachts entering Australian waters from overseas not for yachts cruising within Australian waters.

Recreational craft have also been implicated in the transfer of an introduced goby *Acentrogobius flavimanus* from commercial ports to non commercial ports (Bell *et al*. 1987). It is difficult to document these transfers as there is little if any record kept of movement of fishing boats or recreational boats, in contrast to the detailed inventories maintained for commercial shipping.

While the majority of Australian pest species are from overseas, one potentially could have a species endemic to a particular region of Australia becoming a pest in another region and being transported by local shipping either as a full fouling organism or via ballast water.

Categorisation

Native or introduced

Determining whether or not a species is introduced or native is not necessarily easy. While some species are obviously exotic marine introductions in many cases it is more problematical to determine if a species is native or introduced, especially in areas where the biota is poorly known, which represents a large part of Australia especially for marine invertebrates. In many cases it may just represent a new record for the area, which has not previously been well sampled or represent a species which has been introduced naturally via pelagic larvae dispersed by currents. So how does one distinguish between a natural introduction from a non natural introduction? Just because a species was described from a particular area i.e. the type locality, this does not automatically mean that this is where the species evolved. Determining the native range of a species is difficult and with global warming may be shifting naturally (Sagarin *et al*. 1999). Secondly once a species has been introduced to an area outside of its normal range, whether it becomes a pest or not is difficult to predict. In their native range, some of the species which have been identified as being a pest in Australia such as the fan worm *Sabella spallanzanii* which occurs in the Mediterranean, and is genetically similar to those found in Port Phillip Bay, has not been reported as changing habitats in its native environment. In contrast, the Northern Pacific starfish *Asterias amurenis* is sometimes regarded as a pest on shellfish farms in Japan in its native range (Nojima *et al.* 1986) although not in undisturbed environments.

The serpulid *Hydroides elegans* has been listed as a potential introduced species by Hayes *et al*. (2005) and forms dense colonies at low tide around Port Jackson, Sydney. However, it is not clear if this species should be regarded as an introduction into Sydney Harbour or not. The species was described by Haswell in 1883 as *Eupomatus elegans* from Port Jackson, and has since been recorded from various subtropical ports around the world, (Hong Kong, Cape Town, Rio de Janeiro). Prior to Haswell describing the species, Sydney was subjected to almost 100 years of shipping and so this species could have been imported into Australia, but perhaps, more likely, this is an Australian species which has been dispersed to other countries. Subsequently, several other species have been synonymised with *H. elegans* by Zibrowius (1970) including some European species, so this really confuses the records and thus it may be impossible to determine the origins of these populations around the world (ten Hove pers. comm.).

Pest species

The relatively few species which have been listed as pests (see Hayes *et al.* 2004, 2005) tend to be large and conspicuous such as *Sabella spallazanii*, and *Asterias amurensis* or pose a health risk to humans who have eaten shellfish which have fed on toxic dinoflagellates and accumulated their toxins (Hallegraeff and Fraga 1998). The criteria used by Hayes *et al*. (2005) to identify "priority pests" were "potentially a high risk to human health, the marine environment and/or the commercial interests operating within that environment". They used a deductive analysis that relies on previous invasion history to identify potentially high risk species and these were then ranked according to their impact and invasion potential (Hayes and Sliwa 2003). This implies that we know a lot about their biology and for some of the species listed by Hayes *et al*. (2004) we lack this information. Hayes *et al*. (2005) modified their pest lists from Hayes *et al*. (2004) removing some species previously listed as more information was obtained.

Cryptogenic species

As well as species being identified as pests, others have been labelled as cryptogenic species, which Carlton (1996) defines as a species that is not demonstrably native or introduced. Carlton (1996) suggests that as historical records for most species in most shallow water communities are unavailable and in the absence of a fossil record, it is difficult to determine the origin of many species and he prefers to list such species as cryptogenic. Determining the area where a species evolved or is native to is often difficult, given that many marine species disperse naturally via pelagic larvae. In Australia a large number of species have been listed as cryptogenic species although Hayes *et al*. (2005) have modified their original list of cryptogenic species, following input from appropriate taxonomists.

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Legal situation and current control measures

The numerous studies worldwide and economic damage caused by introductions into marine and freshwater environments by shipping marine introductions such as the Zebra mussel *Dreissena polymorpha* into the Great Lakes and connected waterways in the USA from Europe (Nalepa and Schloesser 1993, Johnson and Carlton 1966), and the collapse of fisheries in the Caspian Sea caused by the ctenophore (*Mnemiopsis leidyi*) (Ivanov *et al*. 2000) and other examples highlighted the economic effects of these introductions. This led to the International Maritime Organisation (IMO) to develop the "International Convention for the Control and Management of Ships Ballast Water & Sediments" which sets out a framework for international ballast water management (http: //globallast.imo.org/index.asp) which will make ballast water management mandatory. Australia is a signatory to the convention, and under commonwealth law, ballast water management has been mandatory for ships coming from overseas in Australia since 2001. It is the intention of all Australian State governments to introduce ballast water management and the Victorian government already has ballast water management in place (www.epa.vic.gov.au/water/ballastwater/obligations.asp).

AQIS is the Federal government agency responsible for checking international shipping as it arrives in Australian waters for introduced species. It determines whether a ship is allowed to discharge ballast water as it takes on board cargo in Australian ports. Each time, ballast water is discharged into a port, potentially it provides another new inoculation of an introduced species, be it a species from another region of Australia or an introduced overseas species. In addition, they may check for hull fouling especially around the anchor and parts of the hull that are difficult to clean and they can order a yacht entering Australian water to be slipped and cleaned at the owners expense.

AQIS has taken a risk management approach to preventing or minimising the introductions of exotic species into Australian waters. Certainly ships which have taken on ballast water in countries where toxic dinoflagellate blooms are occurring have been prevented from deballasting in Australian waters.

In 2000 a bloom of *Gymnodinium catenatum* occurred in an area of New Zealand used for spat collection for a significant part of the NZ shellfish industry. Spat was found to be contaminated with dinocysts and its transfer was banned until Cawthron Institute introduced a hot spa treatment (based on studies undertaken by Hallegraeff *et al.* 1997). This bloom event and the fallout from it, is discussed by Hallegraeff and Gollasch (2006). In addition, no ships were allowed to take on ballast water as discharge into a foreign port could have transferred these toxic dinoflagellates. This was allowed by the International Council for Exploration of the Sea (ICES) Code of Practice on the Introductions and Transfer of Marine Organisms (latest version 2003; see www.ices.dk).

However, the difficulty of determining if ballast water does contain live adults or larvae of potential pests should not be underestimated. It is difficult to test ballast tanks because of the problems of sampling the various layers of the tank, they are not simple rectangular boxes instead they have numerous nooks and crannies where animals can hide, access to the tanks is difficult and sampling the sediment which tends to accumulate at the bottom is difficult (Rigby and Hallegraeff 1994; Hallegraeff and Gollasch 2006). Ships also have a series of ballast water tanks which under ideal conditions should all be sampled but it is costly and time consuming to sample them all and also often difficult to find the appropriate experts to identify the component groups especially for dinoflagellates. In addition many of the groups will be represented by larval stages which may not be identifiable to species until they have settled and metamorphosed into adults.

An Australian program is currently underway to develop genetic probes to easily identify if particular species are present in the water column of the ballast tanks (Gunasekera *et al*. 2005 and reference therein). However this sort of sampling kit is a long way off, being available to the local AQIS officer at an international port. Which genetic markers may be useful is still be explored, currently the gene 28S is being sampled for a range of sabellids including *Sabella spallanzanii* and native species of the family, but as we have very little genetic sequence data for this polychaete family, it is not clear if this is the appropriate gene to be sequenced. Similar problems will arise for all other groups and this certainly is not an option in the immediate future.

Various suggestions have been made as to heating the ballast water but the volumes involved and the degree to which the water must be heated to kill the dormant cysts of dinoflagellates are major impediments, perhaps the next generation of ships built could recycle engine heat through the ballast tanks. Currently ships are encouraged to reballast at sea but this can only be carried out in calm conditions, replacing estuarine/coastal species with oceanic species which are unlikely to survive in coastal waters. Confirming if a ship has reballasted or not is difficult to quickly prove by the Quarantine Officers stationed on shore and the complexities of the ballast tanks suggests that considerable amount of flushing must occur before the majority of the ballast water is exchanged (Rigby and Hallegraeff 1994). So again while this may reduce the risk, AQIS really must rely on a risk assessment and this will be largely based on where the ship has come from and the physical and biological characteristics of that port and the likelihood that the biota of this port can survive in the Australian port (Hilliard *et al.* 1997). For example species living in a temperate port are unlikely to survive in an Australian tropical port. This may explain why tropical Australian ports have to date reported far fewer introductions of pest and cryptogenic species than temperate ones (Hutchings *et al.* 2002) as much of Australia's trading partners are in temperate areas, although this should be carefully monitored if shipping patterns change.

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Case studies of Australian introduced species

Asterias amurensis, which occurs in dense populations in soft bottom communities in sheltered estuarine areas such as the Derwent River, Tasmania and Port Phillip Bay, Victoria, eats anything in its path including commercially important species (Ross *et al.* 2002), and can form dense populations. This species has been reported from several Tasmanian estuaries and it is unclear as to whether this represents a series of independent inoculations in different ports or a single inoculation which has then spread along the coast. The live fish trade has been suggested as the vector for the transport of *A. amurensis* from northern Tasmania to Port Phillip Bay in Victoria, as the adults cannot survive in exposed waters and therefore could not have migrated across Bass Strait. Alternatively as the first adults were seen around mussel ropes in 1995, they may have been transported with relocated mussels (Grannum *et al.* 1996; Hutchings 1999). In reality, it is difficult to prove the method by which they were transported but it seems likely it was not via commercial shipping and currently it is estimated that over 7.5 (± 15SE) million *A. amurensis* occur in Port Phillip Bay as of 2000 (Parry and Cohen 2001). Genetic data indicate that populations of *A. amurensis* in Port Phillip Bay are closely related to those found in Tasmania (Murphy and Evans 1998) and do not represent another introduction from its native northern Pacific. The species can rapidly build up large populations as females spawn 100's of thousands of eggs per spawning (Nojima *et al.* 1986). Now that the species is well established within Port Phillip Bay, the major fear is that it will transported to other protected bays along the mainland coast especially Western Port or Upper Spencer Gulf. Based on what is known about their temperature tolerances it could potentially establish populations as far north as Sydney (Sutton and Bruce 1996). Potential vectors include domestic shipping or transfer by fishing activities.

A recent study has shown that Australian scallops *Pecten fumatus* and *Chlamys asperrima* take avoiding reaction when touched by the native starfish *Coscinasterias muricata* and immediately elicit an escape response, whereas when touched by *Asterias amurensis* they almost always fail to undertake an escape response (Hutson *et al.* 2005). This suggests that escape responses in invertebrates has evolved relative to predation risk and the absence of predator recognition may have serious consequences for wild and farmed populations of scallops in southern Australia where *A. amurensis* is present.

Sabella spallanzanii modifies the environment surrounding the colony as it effectively vacuums the water column altering the suite of organisms that settle in amongst the dense tubes (Currie *et al.* 2000; Holloway and Keough 2002a, b; O'Brien et al. 2006). The dense populations of *Sabella spallanzanii* in Port Phillip Bay have now crashed and while they have spread within the Bay they are restricted to sheltered, nutrient-enriched waters (Currie *et al.* 2000). This supports the suggestions by Moyle and Light (1996) that physical factors and levels of disturbance are more important than biological factors in determining the success of introduced species.

Another introduced species which can cause major ecological impact by effectively smothering all other benthic organisms is the black lipped mussel *Mytilopsis sallei*. This species arrived in Darwin either on the hull of international cruising yacht or an unidentified Indonesian fishing boat (Pyne 1999; Hutchings *et al.* 2002) and subsequently infected yachts from the Darwin marina were found along the east Australian coast (Hutchings *et al.* 2002; Willan *et al.* 2000). This species was successfully eradicated from the Port of Darwin (Willan *et al.* 2000) at a cost of > US $1.6m. Eradication was greatly facilitated by the fact that the mussel was confined to a marina which is closed with boom gates as the tide falls allowing chemical to be contained during a tidal cycle killing off the mussels. The mussel had not spread to nearby areas in Darwin Harbour.

The goby *Acanthogobius flavimanus* was first recorded from Sydney Harbour in 1971 (Hoese 1973), then recorded from Botany Bay in the late 1970s and the Hawkesbury in 1984 (Middleton 1982, Bell *et al.* 1987, Lockett and Gorman 2001). However, it has not appeared to have expanded its distribution since (Lockett pers. comm.). Factors such as a lack of reproductive success due to unfavourable temperature regimes, a lack of suitable habitat, and competition from native species, have been suggested as reasons as to why this species has not spread (Hoese 1973; Middleton 1982). It seems likely that the species is preyed upon, but to what extent is unknown, and also it probably interacts with native species, but the extent of these interactions is difficult to quantify (Lockett pers. comm.).

Assigning species to the pest or cryptogenic lists

Species listed as pests by Hayes *et al.* (2005) tend to be species which can impact on commercially important species either by competing for space or food resources. They suggest the need for a transparent, rigorous and defensible approach to identifying priority target species as an essential component of any system designed to manage aquatic invasive species within a nations border (Hayes *et al.* 2005). These concepts are laudable yet I would suggest that for many of the species listed in Hayes *et al.* (2005) we lack sufficient information about their precise distribution, their biology and even in some cases there taxonomic status.

Many of the species listed as cryptogenics by Hayes *et al* (2005) are small and often resemble native species or belong to genera represented in Australian waters, and are typically subtidal species. Identification of these species and their true status as to whether they represent an undescribed species or an introduced species is often problematical given our lack of knowledge of Australia's marine biodiversity particularly in tropical waters.

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Port surveys

In order to document marine introductions into Australia, during the 1990s and early 2000, extensive sampling of our international ports were carried out (Hewitt and Martin 2001). A number of introduced species was detected, although, for most ports, a large proportion of the fauna was not identified to species due to time and financial constraints. These surveys highlighted the large number of introductions but also the problems of identifying our biota. Basically, the agencies undertaking the surveys using a standardized protocol, were asked to check if species, regarded as a pest or a cryptogenic species, were present as listed by Hewitt and Martin (2001). In some cases this meant that those families in which these species occurred were extracted from the samples and identified to species. This is certainly the procedure employed by the Australian Museum which conducted the survey of the Port of Sydney (AMBS 2002). An exception was Port Phillip Bay, where the fauna was almost completely identified to species (Hewitt *et al.* 2004). This species list, and more importantly, the material compared with the extensive collections made during the 1969-1971 survey of Port Philip Bay (Poore *et al.* 1975), and new introductions, were documented and changes to the faunal composition and comments on the functioning of these benthic communities were made (Hewitt *et al.* 2004). In a couple of cases, material was misidentified from the 1969-1971 survey that was found to be an introduced species. This highlights the value of baseline studies and the deposition of material in a state museum, so it can be re-examined as new information comes to light. As we undertake systematic studies, sibling species are often highlighted and our understanding of the sorts of characters useful to distinguish species increases. In the ideal world, all species collected during such port surveys should be identified to species. Australia has a shortage of marine taxonomists and, for some groups no Australian experts exist. The aging and greying proportion of our population of taxonomists will increase unless immediate steps are taken to increase funding to Australian museums. Despite this need, funding for such research is decreasing. One positive outcome of these port surveys is the National Heritage Trust grant awarded to museums to house these collections, which means that representative collections from all port surveys have been deposited in the relevant State museums. Specimens in these collections identified as pests or cryptogenics have been verified and entered into Online Zoological Collections of Australian Museums (OZCAM), which are available via the web. This will help in clarifying the distribution of these species based on actual specimens, and it can be used as a benchmark from which future expansions or contractions can be tracked. The material is also available to taxonomists and, as revision of groups occur, it may lead to a re-evaluation of species previously regarded as pests or cryptogenics, and additional introduced species may also be found.

One should not underestimate our limited knowledge of the biota of our tropical ports and perhaps with more detailed sampling more introductions will be found. During the recent port surveys carried out during the late 1990s and early 2000 some tropical ports were sampled for the first time (Hewitt and Martin 2001, Neil *et al.* 2004). To date one of most important ports in terms of shipping movements and volume of ballast water, Dampier in Western Australia, has not been systematically sampled for the detection of pests and cryptogenic species, whereas all other major ports in Western Australia have been sampled.

Action required

Species already introduced into Australian waters are unlikely to disappear, and we can expect more to arrive. Probably the majority of species discharged either as adults or as larval/juvenile or resting stages never survive or if an individual survives they fail to establish viable populations. Even then these populations may never be detected or if they do, they may be benign or appear to be benign. We should not be complacent as some of the species that have become established have proved to be costly not only in terms of altering the marine ecosystem but impacting on aquaculture ventures. In most cases we have little idea of the impact that introduced species are having. Only when a species has a major impact on aquaculture or human health is it likely that sufficient funds will be made available to eradicate or control the species. Three strategies need to be pursued, while attempting to restrict additional species from arriving. Stricter controls on aquaculture, and live fish trade, secondly try to study the impact that existing introductions are having on native marine ecosystems, and finally we need to be able to recognise new introductions before they have established large populations, in reality the only window of opportunity when they can be eliminated. This requires marine taxonomists to closely work with local communities, which are most likely to identify a new "species", which may represent a new record of a native species to the area or an introduced species. In both cases a closer study is warranted. However, unless State Museums are better supported, an appropriate taxonomist may not exist.

In addition we need to continue studies which attempt to predict which species may become pests (e.g. Williamson and Fitter 1996), and estimate rates at which introduced species could spread (Hastings 1996; Williamson and Fitter 1996 and references therein). What are the characteristics of pest species, and how do they impact on our marine ecosystems? Carlton and Geller (1993) have suggested that the scale of introductions may lead to profound changes in marine ecosystems as currently being witnessed in the Derwent estuary (Ross *et al.* 2002).

Are marine ecosystems already impacted by other anthropogenic influences more likely to be amenable to introduced species becoming established and becoming pests? We really do not know. Certainly by the time they have become pests it is probably too late for them to be eliminated. The eradication of *Mytilopsis sallei* in Darwin

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Harbour was almost a freak event and if it had become established in the surrounding areas, its eradication would have been impossible. These predictions are based on the failure to eradicate either the cane toad *Bufo marinus* or the rabbit *Oryctolagus cuniculus* both relatively large and easy to identify by both specialists and the general public, even though considerable funds have been spent trying to eradicate them. So what we can we do? Basically the only available options are to minimise the risk of their introductions.

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References

Australian Museum Business Services (AMBS) 1997. *Ability of Target Organisms to Survive in Ballast Water.* Report prepared for AQIS.

Australian Museum Business Services (AMBS) 2002. *Port Surveys for Introduced marine species*—Sydney Harbour Final Report. 146 pp.

Bell, J.D., Steffe, A.S. and Talbot, R.B. 1987. The Oriental Goby *Acanthogobius flavimanus*, colonises a third estuary in New South Wales, Australia. *Japanese Journal of Ichthyology* **34**: 227-230.

Carlton, J.T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. *Oceanography and Marine Biology. An Annual Review* **23**: 313-371.

Carlton, J.T. 1987. Patterns of transoceanic marine biological invasions in the Pacific Ocean. *Bulletin of Marine Science* **41**: 452-465.

Carlton, J.T. 1996. Biological invasions and cryptogenic species. *Ecology* **77(6):** 1653-1655.

Carlton, J.T. and Geller, J. B. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. *Science* **261**: 78-82.

Carson, J. and Handlinger, J. 2006. Virulence of the aetiological agent of goldfish ulcer disease in Atlantic salmon, *Salmo salar* L. *Journal of Fish Diseases* **11(6):** 471-479.

Coles, S.L. and Eldridge, L.G. 2002. Nonindigenous species introductions on coral reefs. *Pacific Science* **56:** 191-209.

Currie, D.R., McArthur, M.A. and Cohen, B.F. 2000. Reproduction and distribution of the invasive European fanworm *Sabella spallanzanii* (Polychaeta: Sabellidae) in Port Phillip Bay, Victoria, Australia. *Marine Biology* **136[4]**: 645-656.

Dickman, C R. 2007. The complex pest: interaction webs between pests and native species. Pp 208-215 in *Pest or Guest. The Zoology of Overabundance*, edited by D. Lunney, P. Eby, P. Hutchings and S. Burgin. Royal Zoological Society of NSW, Mosman, NSW.

Didham, R.K., Tylianakis, J.M., Hutchison, M.A., Ewers, R.M. and Gemmell, N.J. 2005. Are invasive species the drivers of ecological change? *Trends in Ecology and Evolution* **20(9):** 470-474.

Farnsworth, E, J. 2004. Patterns of plant invasions at sites with rare plant species throughout New England. *Rhodora* **106**: 97-117.

Grannum, R.K., Murfet, N.B., Ritz, D.A. and Turner, E. 1996. The distribution and impact of the exotic seastar *Asterias amurensis* (Lütken), in Tasmania. In: *The introduced northern Pacific seastar, Asterias amurensis (Lútken), in Tasmania*. Australian Nature Conservation Agency, Canberra, p 53-138.

Gunasekera, R.M., Patil, J.G., McEnnulty, F.R. and Bax, N.J. 2005. Specific amplification of mt-CO1 gene of the invasive gastropod *Maoricolpus roseus* in planktonic samples reveals a free-living larval life-history stage. *Marine and Freshwater* **56**: 901-912.

Hallegraeff, G.M. and Bolch, C.J. 1992. Transport of dinoflagellate cysts in ship's ballast water: Implications for plankton biogeography and aquaculture. *Journal of Plankton Research* **14**: 1067-1084.

Hallegraeff, G.M. and Fraga, S. 1998. Physiological ecology of the toxic dinoflagellate *Gymnodinium catenatum*, with emphasis on bloom dynamics in Tasmania and Spain. In: D.M.Anderson, A.D.Cembella and G.M.Hallegraeff (eds), *Physiological ecology of harmful algal blooms*. Proceedings NATO ASI Workshop, Bermuda, **June 1996**

Hallegraeff, G.M. and Gollasch, S. 2006. Potential Intoductions of microalgae. In Ecology of Harmful Algae edited Granéli E. and Turner, J.T. *Ecological Studies* Vol. **189**:

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

Hastings, A. 1996. Model of spatial spread: is the theory complete? *Ecology* **77**: 1675-1679.

Haswell, W.A. 1883. On some new Australian tubiculous annelids. *Proceedings of the Linnean Society of New South Wales* **7**: 633-638.

Hayes, K. and Sliwa, C. 2003. Identifying potential marine pests- a deductive approach applied to Australia. *Marine Pollution Bulletin* **46**: 91-98.

Hayes, K., Sliwa,C., Migus, S. and McEnnulty, F. 2004. *National Priority Pests-* Part II: Ranking of Australian Marine Pests. Final Report (Draft) for the Department of Environment and Heritage. CSIRO Marine Research, Hobart, Tasmania.

Hayes, K., Sliwa,C., Migus, S., McEnnulty, F. and Dunstan, P. 2005. *National Priority Pests-* Part II: Ranking of Australian Marine Pests. An independent report undertaken for the Department of Environment and Heritage. CSIRO Marine Research, Hobart, Tasmania.

Hewitt, C.L. and Martin, R.B. 2001. Revised protocols for baseline port surveys for introduced marine species- design considerations, sampling protocols and taxonomic sufficiency. *CRIMP Technical Report* No 22. CSIRO Marine Research, Hobart.

Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B., Boyd, S., Cohen, B.F., Currie, D.R., Gomon, M.F., Keough, M.J., Lewis, J.A., Lockett, M.M., Mays, N., McArthur, M.A., O'Hara, T., Poore, G.C.B., Ross, D.J., Storey, M.J., Watson, J.E. and Wilson, R.S. 2004. Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. *Marine Biology* **144**: 183-202.

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Hilliard, R.W, Hutchings P.A., and Raaymakers, S., 1997. Ballast Water Risk Assessment for 12 Queensland Ports. Stage 4–Report. Review of Candidate Risk Biota. *EcoPorts Monograph Series* **No. 13**, Ports Corporation of Queensland, Brisbane 60pp.

Hoese, D.F. 1973. The introduction of the gobiid fishes *Acanthogobius flavimanus* and *Tridentiger trigonocephalus* into Australia. *Koolewong* **2**: 3-5.

Holloway, M.G. and Keough, M.J. 2002a. An introduced polychaete affects recruitment and larval abundances of sessile invertebrates. *Ecological Applications* **12 (6):** 1803-1823.

Holloway, M.G. and Keough, M.J 2002b. Effects of an introduced polychaete, *Sabella spallanzanii*. *Marine Ecology Progress Series* **236:** 137-154.

Hutchings, P.A. 1993. Ballast water introductions of exotic marine organisms into Australia. Current Status and management options. *Marine Pollution Bulletin, Special issue* **25:** 196–199.

Hutchings, P.A. 1999. The limits to our knowledge of introduced marine invertebrates. Pp 26-29 in *The Other 99%. The Conservation and Biodiversity of Invertebrates,* edited by W. Ponder and D. Lunney. Transactions of the Royal Zoological Society of New South Wales, Mosman, NSW.

Hutchings, P.A., Hilliard, R.W. L. and Coles, S., 2002. Species Introductions and Potential for Marine Pest Invasions into Tropical Marine Communities, with Special Reference to the Indo–Pacific. *Pacific Science* **56(2):** 223–233.

Hutson, K.S., Ross, D.J., Day, R.W. and Ahern, J.J. 2005. Australian scallops do not recognise the introduced predatory seastar *Asterias amurensis*. *Marine Ecology Progress Series* **298**: 305-309.

Ivanov, V.P., Kamakin, A.M., Ushivtzev, V.B., Shiganova, T., Zhukova, O., Aladin, N., Wilson, S.I., Harbison, G.R. and Dumont, H.J. 2000.Invasion of the Caspian Sea by the comb jellyfish *Mnemiopsis leidyi*. *Biological Invasions* **2**: 255-258.

Johnson L.E. and Carlton, J.T. 1996. Post-establishment spread in large scale invasions: dispersal mechanisms of the Zebra mussel *Dreissena polymorpha*. *Ecology* **77**: 1686-1690.

Kerr, S. 1994. *Ballast Water Ports and Shipping Study*. Ballast Water Research Series Report No. 5. AQIS and Bureau of Resource Sciences, Canberra.

Knight-Jones, P. and Knight-Jones, E.W. 1979. Spirorbidae (Polychaeta Sedentaria) from Alaska to Panama. *Journal of Zoology, London* **189**: 419-458.

Knight-Jones, E.W., and Knight-Jones, P. 1980. Pacific spirorbids in the East Atlantic. *Journal Marine Biological Association of the UK.* **60**: 461-464.

Langdon, J. S., 1989. Prevention and control of fish diseases in the Murray-Darling Basin. In *Proceedings of the workshop on native fish management, Canberra, 16-18 June 1988*. Murray-Darling Basin Commission, Canberra.

Lockett, B.M. and Gorman, M.F. 2001. Ship mediated fish invasions in Australia: two new introductions and a consideration of two previous invasions. *Biological Invasions* **3**: 187-192.

Lodge, D.M. 1993. Biological Invasions: Lessons for Ecology. *Tree* **8(4)**: 133-137.

MacDougall, A.S and Turkington, R. 2005. Are invasive species the drivers or passengers of change in degraded ecosystems? *Ecology* **86**: 42-55.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M. and Bazzaz, F. 2000. Biotic Invasions: Causes, Epidemiology, Global Consequences and Control. *Issues in Ecology* **5**: 1-20 Publication of Ecological Society of America.

Middleton, M.J 1982. The oriental goby *Acanthogobius flavimanus* (Temnick and Schlegel), an introduced fish in the coastal waters of New South Wales, Australia. *Journal of Fish Biology* **21**: 513-523.

Moyle P. B. and Light, T. 1996. Fish invasions in California: do abiotic factors determine success? *Ecology* **77**: 1666-1670.

Murphy, N. and Evans, B., 1998. Genetic origin of Australian populations of *Asterias amurensis*. In: Goggin, L.C (ed) *Proceedings of a meeting on the biology and management of the introduced seastar Asterias amurensis in Australian waters. CSIRO Division of Marine Research, Hobart, pp. 22-25.*

Nalepa, T.F. and Schloesser, D.W. 1993. Editors. *Zebra mussels: biology, impact, and control.* Lewis (CRC Press) Ann Arbor, Michegan, USA.

Nell, J.A., Smith, I.R. and McPhee, C.C. 2000. The Sydney rock oyster *Saccostrea glomerate* (Gould 1850) breeding programme: progress and goals. *Aquaculture Research* **31**: 45-49.

Neil, K.M., Hutchings, P.A. and Stafford, H., 2004. Port surveys for non-indigenous species - the benefits of taxonomic networks. *Journal of Marine Science and Environment* **1**: 11-17.

Nojima S., El-Sayed Soliman, F., Kondo, Y., Kuwanao Y., Nasu, K. and Kitajima, C. 1986. Some notes on the outbreak of the sea star *Asterias amurensis versicolor* Sladen, in the Ariake Sea, western Kyushu. Publications *Amakusa Marine Biology Laboratory* 8: 89-112.

O'Brien, A.L., Ross, A.J., and Keough, M.J. 2006. Effects of *Sabella spallanzanii* physical structure on soft sediment macrofaunal assemblages. *Marine and Freshwater Research* **57**: 363-371.

Parry, G.D. and Cohen, B.F. 2001. The distribution, abundance and population dynamics of the exotic seastar *Asterias amurensis* during the first three years of its invasion of Port Phillip Bay. *Report No. 33, Marine and Freshwater Research Institute, Queenscliffe.*

Pollard, D.A. and Hutchings, P.A., 1990a. A review of exotic marine organisms introduced to the Australian region, 1. Fishes. *Proceedings of the Asian Fisheries Society's Darwin Workshop, August 1988*. *Asian Fisheries Science* 3: 205–221.

Pollard, D.A. and Hutchings, P.A., 1990b. A review of exotic marine organisms introduced to the Australian region. 2. Invertebrates and Algae. *Asian Fisheries Science 3*: 223–250.

Poore, G.C.B., Rainer, S.F., Spies, R.B. and Ward E 1975. The zoobenthos program in Port Phillip Bay, 1969-1973. *Fish Wildlife Technical Papers*. **7**: 1-78.

Pyne R. 1999. The black-striped mussel (*Mytiliopsis sallei*) infestation in Darwin: A clean up strategy. *EcoPorts Monograph Series No*. 19: 77-83.

Rigby, G.R. and Hallegraeff, G.M. 1994. The transfer and control of harmful marine organisms in shipping ballast water: Behaviour of marine plankton and ballast tank exchange trials on the MV "Iron Whyalla". *Journal of Marine Environmental Engineering* **1**: 91-110.

Ross, D.J., Johnson, C.R. and Hewitt, C.L. 2002. Impact of introduced seastars *Asterias amurensis* on survivorship of juvenile commercial bivalves *Fulvia tenuicostata*. *Marine Ecology Progress Series* **241**: 99-112.

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Sagarin, R.D., Barry, J.P., Gilman, S.E. and Baxter, C.H. 1999. Climate related change in an intertidal community over short and long time scales. *Ecological Monographs* **69**: 465-490.

Sutton, C. A. and Bruce, B. D. 1996. *Temperature and Salinity Tolerances of the Larvae of the Northern Pacific Seastar Asterias amurensis*. Technical Report No. 6, (Centre for Research on Introduced Marine Pests), CSIRO, Division of Fisheries, Hobart.

Thomson F.K., S.A. Heinemann, and F.C. Dobbs, 2003. Patterns of Antibiotic Resistance in Cholera Bacteria Isolated From Ships' Ballast Water. *Proceedings of the Third International Conference on Marine Bioinvasions*, La Jolla, California, March 16-19, 2003, p. 118.

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

Williams, R.J., Griffiths, F.B., Van der Wal, E.J. and Kelly, J. 1988. Cargo vessel ballast water as a vector for the transport of non-indigenous marine species. *Estuarine Coastal and Shelf Science* **26**: 409-420.

Williamson, M. and Fitter, A. 1996. The varying success of invaders. *Ecology* **77:** 1661-1666.

Zibrowius, H. 1970 (1971). Les espèces Méditerranéennes du genre *Hydroides* (Polychaeta Serpulidae) remarques sur le prétendu polymorphisme de *Hydroides uncinata*. ***Tethys*** **2**(3): 691-746.

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