Introduced species
in tropical waters

CURRENT STATE OF KNOWLEDGE
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The introduction of invasive species into new marine environments is considered one of the greatest threats to the world's oceans. More than 250 exotic marine species are reported from Australian waters, most of which were introduced unintentionally via shipping activities and mariculture. Despite the hundreds of introduced species in Australian waters, only a few of them are considered pests because they have a major impact on the environment, economy, human health or amenity.

Research and government initiatives are focussed on decreasing the risk of introducing marine species into Australian waters, reducing the numbers and spread of those that have already established, and ameliorating their impacts.

Arrival of marine species

Shipping

As an island nation, Australia is particularly vulnerable to the introduction of exotic species through shipping. Each year, more than 11,000 vessels from 600 overseas ports visit Australia's 65 major ports. Most shipping trade with Australia originates in south-east Asia, with ships making regular and repeated voyages. The enormous volume of trade with this region, and the similarity of marine environments, increases the risk of introducing marine species.

In 2002-03, about 500 international yachts visiting Australia arrived into Queensland ports. Many small vessels also move across Torres Strait. In addition, apprehended vessels such as foreign fishing vessels and suspected illegal immigrant vessels are towed into ports in tropical Australia. These vessels can unintentionally provide a mechanism (or vector) for introducing exotic plants and animals into new environments by transporting them across oceans – either as fouling or in ballast water.

Photo by Tourism Queensland

Hulls of recreational vessels can be fouled with the growth of marine organisms.

Fouling

The growth of marine organisms on artificial surfaces, including vessels' hulls and internal spaces, is called 'fouling'. Both recreational and commercial vessels can carry exotic species as fouling on their hulls or internal seawater systems. Heavily fouled vessels can carry up to 5kg of fouling material per square metre of exposed surface. Most exotic species carried as fouling will not survive the journey. But, if conditions are right, the exotic species carried as fouling by both recreational and commercial vessels can be released or spawn and establish in the new locations.

Ballast water

Marine organisms once travelled across oceans inside ships, together with wet rocks, sand or gravel, which were used as ballast to stabilise the vessel at sea. With advances in modern shipping, the speed and distance that marine species can be transported has increased dramatically.

Modern steel ships now carry water rather than rocks as ballast. Every day, it is estimated that around 7,000 different marine species including viruses, bacteria, and small marine invertebrates, are transported around the world in ballast water.

Most of Australia's trade in bulk commodities is carried by ships. It is estimated that more than 150 million tonne of ballast water is discharged into Australia's major ports each year.

The short transit time between Australian and Asian ports (often less than 20 days) allows many organisms to survive the voyage. For example, toxic dinoflagellate algae can survive in ballast water for weeks. Dinoflagellates can accumulate in mussels, oysters and scallops and, when eaten, cause paralytic shellfish poisoning in humans.

Therefore, there is an enormous risk that exotic marine species could establish in Australian waters with ports and harbours particularly at risk because they are usually the first place where a pest arrives.

Other mechanisms

Exotic marine species can also be introduced when released unintentionally from public or private aquaria. For example, the green algae *Caulerpa taxifolia*, a popular marine aquarium plant, was introduced to the Mediterranean Sea from a public aquarium and has become a serious pest. The alga is native to the tropics including the West Indies, and tropical African and Australian coasts. In Australia, several varieties of *Caulerpa* were found in waterways

Photo by Sven Uthicke

Caulerpa taxifolia, a native to tropical Australian waters, has been found further south.

around Sydney and Adelaide. The sources of these algae are not yet known but it is thought that they originated from native Queensland populations, transported by local boating traffic or the aquarium trade.

Some exotic organisms were deliberately introduced into Australia for aquaculture. For example, in 1947, the Pacific oyster *Crassostrea gigas* was imported into Tasmania and Western Australia for aquaculture. It was later introduced deliberately into Victoria and South Australia. The Pacific oyster is a highly invasive species and competes for space occupied by native oysters. It has spread into New South Wales where it is listed as a noxious species in all state waters except Port Stephens (where it is cultured). In Tasmania, the Pacific oyster is cultured and is not considered a pest. To prevent the spread of introduced species around Australia, there are now strict regulations on the import and movement of marine species for aquaculture.

An international problem

Introduced marine species are a global problem. The soft coral *Carijoa riisei* from the Caribbean has invaded deep coral beds in Hawaii. Enormous populations of this soft coral grow down to 120m and have overgrown and killed colonies of black coral that were once abundant at this depth.

Australian waters have also been the source of species that have been introduced overseas. For example, the barnacle *Elminius modestus* and the red algae *Asparagopsis armata* were introduced from Australia into Europe, and the jellyfish *Phyllorhiza punctata* introduced into Hawaii.

Introduced marine species in Australia

More than 250 marine species have been introduced into Australian waters from around the world. Many of these species remain inconspicuous, but a few have established large populations and become pests. It is estimated that one in each six to 10 introduced marine species will become a pest.

Pests are defined as species that are likely to have a major impact in a new environment on economy, environment, human health or amenity. Species that have been invasive elsewhere are often considered a high risk of becoming pests in Australia.

About 15 introduced species are already considered pests in Australian waters. These include toxic dinoflagellates *Alexandrium minutum* and *Gymnodinium catenatum*, the Japanese kelp *Undaria pinnatifida*, the northern Pacific seastar *Asterias amurensis*, the Pacific oyster *Crassostrea gigas*, the European fan worm *Sabella spallanzanii* and the European green crab *Carcinus maenas*. A further 32 species are considered potential pests although they have not yet established in or reached Australia. These potential pests are listed on Australia's Next Pest List and include the black-striped mussel *Mytilopsis sallei* and the Asian green mussel *Perna viridis*.

The **black-striped mussel** *Mytilopsis sallei* was found in Darwin harbour in 1999. It was probably introduced on the hull or in the seawater piping of a recreational vessel from overseas. The black-striped mussel is closely related to the zebra mussel *Dreissena polymorpha* which was introduced in ballast water into rivers and lakes in north America. The zebra mussel chokes waterways and pipes and occupies large areas of habitat where native organisms formerly grew. Removal of zebra mussels and remedial engineering in the United States costs US $750 million annually. Fortunately, the black-striped mussel was detected in Darwin harbour and eradicated in an operation that cost more than $2 million. There would have been ongoing economic costs if this species had not been eradicated because it would need to be regularly removed from vessels, outlet pipes and other structures. The black-striped mussel also could have devastated northern Australia's pearling industry (worth about $225 million p.a.) by colonising pearl oyster culture structures such as ropes, floats and nets.

In 2001, the **Asian green mussel** *Perna viridis* was found on a vessel's hull in Cairns harbour in Queensland. This mussel is not native to these waters. It is considered a potential threat and is included on the Next Pest List. The discovery caused concern because, in other parts of the world including India, China and Florida, populations of the Asian green mussel can grow quickly and cover underwater walls, boat hulls and intake pipes. If these mussels were to establish in Cairns harbour, the commercial value of the port could be detrimentally affected and the mussels could compete with native fauna.

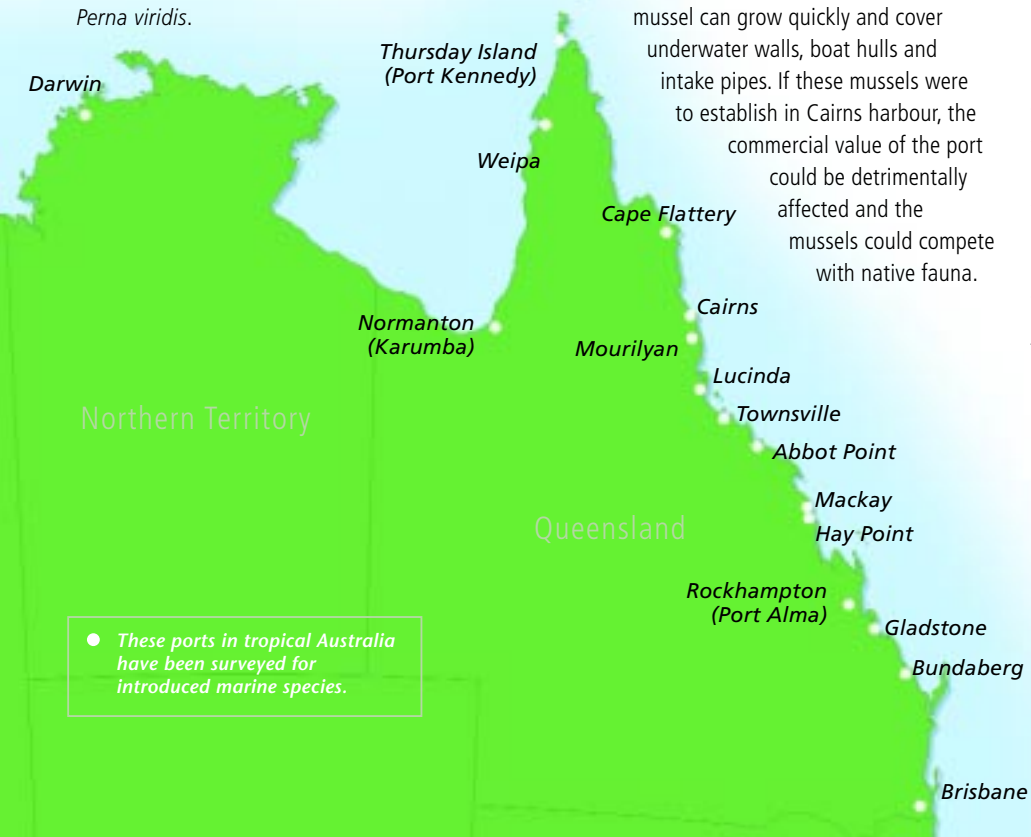


Photo by DPI


Photo by DPI

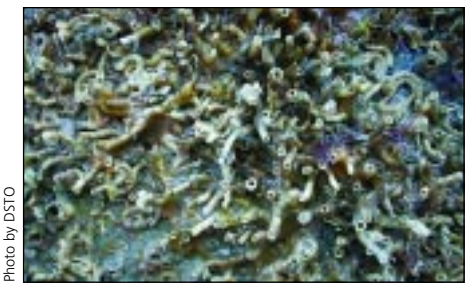
Photo by DSTO

Top: Black striped mussel
Middle: Asian green mussels
Bottom: Caribbean tube worms

Commonwealth, State and local agencies worked together on an emergency operation in Trinity Inlet to remove the Asian green mussel. Divers surveyed the area to establish the extent of the infestation, and potentially infected vessels were inspected and decontaminated. An eradication response was developed following studies of the mussel's biology and ecology. This information was also used to determine the likely spread of the mussel during routine port activities such as dredging. Monitoring will be continued to ensure that any further occurrence of the Asian green mussel in Cairns harbour is detected.

The **Caribbean tubeworm** *Hydroides sanctaecrucis* has also been introduced into Cairns harbour and other Australian ports and marinas. It is a native of the Caribbean and inhabits muddy coastal lagoons. The tubeworm is not listed on the Australian pest list because it has not established in pest numbers in any location. However, it is a nuisance for vessel owners because it builds calcareous tubes on hard surfaces such as boat hulls which can reduce the boat's performance and speed, and increase costs of maintenance.

Spreading introduced marine species around Australia

There is a great risk that introduced species will be spread around Australia when they establish dense populations. For example, the **northern Pacific seastar** *Asterias amurensis* was introduced, probably in ballast water, to the Derwent estuary in Tasmania in the early 1980s. This pest is a voracious predator and threatens populations of native species, as well as commercial shellfish industries. There were tens of millions of these seastars in the Derwent estuary and, during the breeding season, densities of northern Pacific seastar larvae were the highest reported for any seastar in the world. Therefore, there was a great risk that ballast water taken onboard in the Derwent estuary would contain the larvae of these marine pests and transfer them to other ports. This risk was realised in 1998 when northern Pacific seastars were found in Port Phillip Bay, Victoria. Genetic studies indicate that the seastars in Victoria originated in Tasmania. In only a few years, there were more than 100 million of the seastars in Port Phillip Bay, showing the explosive population increase of this species.

Recreational vessels can also spread exotic marine species around Australia. There are about 16,500 recreational vessels more than 6m long in Queensland that can carry marine species on their hulls and internal seawater systems. Yachts do not have to moor for long periods in some marinas to acquire fouling organisms. Between two and 19 times more marine organisms will settle on surfaces in marinas that have permanent breakwalls around them than in unenclosed marinas or open-water anchorages. Therefore, recreational vessels can spread marine invaders around the Australian coast if they are not treated appropriately to prevent the growth of fouling organisms. For example, self-polishing anti-fouling paints are intended for use on boats that move regularly or frequently. Recent research has found many yachts that use these paints actually spend long periods tied to the dock. Therefore, to minimise the risk of transferring pests via hull fouling, it is important to paint hulls with an appropriate anti-fouling paint and re-coat regularly in accordance with manufacturer's instructions.

Renewing the anti-fouling paint on vessels is expensive and boat owners sometimes opt for cheaper ways to clean their hulls. Scrubbing the hull while the boat is in the water can be a quick way to rid the boat of unwanted growth. However, research has shown that in the long-term, scrubbing might not produce the desired benefits because small traces of marine animals such as tubeworms, barnacles and sponges are left behind. These can quickly spread over cleaned surface in the absence of competition or attract other marine organisms. In-water scrubbing can also dump potential problem species in ports or marinas, and damage anti-fouling paint on the hull, minimising its effectiveness.

In 1997, Australia and New Zealand jointly issued a code-of-practice for in-water hull cleaning and maintenance that applies to all Australian waters. It prohibits the in-water cleaning of vessels' hulls in ports, marinas and waterways without approval. The code-of-practice is intended to prevent fouling organisms that are scraped from vessels being established and also to limit the release of toxic anti-fouling material.

Surveys for introduced marine species

To determine the distribution and abundance of introduced marine species, researchers survey ports and adjacent areas. The surveys also record the diversity of native marine communities.

In Australia, protocols for port surveys were developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to ensure that different agencies use standardised methods when conducting a baseline survey for marine pests. The sampling techniques are designed to ensure that results from different surveys can be compared and that a representative sample of organisms from the natural and constructed habitats in ports and surrounding areas are collected. The CSIRO protocols have been adopted by the International Maritime Organization (IMO) GloBallast Programme to ensure that similar techniques are used in port surveys around the world so that results are comparable between countries.

Photo by DPI

Samples are scraped from underwater structures during port surveys.

Tropical port environments differ from those in temperate waters. Therefore, the sampling techniques used for tropical ports are slightly different from the protocols developed by CSIRO. Up to 15 different sampling techniques are used during surveys of tropical ports including video recordings, sediment grabs, scrapings from wharf pilings and plankton tows. Samples are also taken to check environmental conditions including water salinity, turbidity, temperature and pH.

Researchers from CSIRO, Coastal CRC and CRC Reef have surveyed many ports in tropical Australia including Darwin, Gove, Karumba, Weipa, Thursday Island, Cape Flattery, Cairns, Mourilyan Harbour, Lucinda, Townsville, Mackay, Hay Point, Port Alma (Rockhampton), Gladstone, Bundaberg and Brisbane (as well as many other ports around Australia).

These surveys show there is a rich and diverse marine community in many Australian ports. For example, a survey in and around the Port of Townsville in November 2000, collected more than 1,300 different marine plants and animals. Three introduced crustaceans were found but these are not considered to be a threat to native communities. No introduced marine species which are considered pests in Australian waters were found.

One port survey enabled authorities to respond rapidly to an invasion by a marine pest and prevent it becoming established. The black-striped mussel was found during a routine survey in Darwin port. Early detection of the pest enabled the Northern Territory Government to initiate a rapid response and eradicate the mussel before it became established (see summary above).

Protecting our coastal environments

Australia is developing a national system to prevent and manage incursions by marine pests. The system outlines strategies for prevention as well as emergency response, monitoring, targeted research, and education and training. State and Australian Government agencies will work together to implement the national system. Currently, the Australian Quarantine and Inspection Service (AQIS) is Australia's lead agency for preventing the introduction of marine pests into Australia.

Fouling

Fouling organisms growing on ships' hulls increase drag, and decrease performance and speed of a vessel. Therefore, 'anti-fouling paints' were developed to protect vessels' hulls from being colonised by fouling organisms. Some anti-fouling paints contain chemicals that prevent the juvenile stages of marine plants and animals from settling. Some anti-fouling paints contained organotin-based compounds such as tributyltin (TBT) which were later realised to be harmful to the environment. Therefore, TBT paints have been banned since July 2003 from use on vessels being repainted in Australia. An international convention is also being negotiated to ban the use of these compounds on all ships on international voyages.

Currently, the fouling on most international vessels entering Australian ports is not inspected to prevent entry of exotic marine species. However, vessel fouling will become part of the regular quarantine inspection for vessels entering Australian ports under the national system that is being developed.

Since the discovery of the black-striped mussel *Mytilopsis sallei* in Darwin Harbour, the Northern Territory Government inspects international yachts entering these waters that intend to enter a marina. If the vessel has not been anti-fouled after entering Australian waters, the hull must be inspected, cleaned as required and the internal seawater systems treated. If the vessel has been anti-fouled in Australia, then only the internal seawater system needs to be treated. The Northern Territory Government also has an arrangement with Australian Government agencies to inspect apprehended vessels.

Photo by DSTO

Australia is developing protocols to screen small international vessels for introduced marine species.

Queensland and Western Australia have similar interim arrangements with Australian Government agencies for apprehended vessels brought into waters of those states. Queensland is also developing national protocols for screening small international and apprehended vessels entering Australian waters, to minimise the risk of pests being introduced by this mechanism in the future. The Australian Quarantine and Inspection Service (AQIS) is testing aspects of the protocols with anticipated introduction for these vessels from July 2004.

Ballast water

The Australian Quarantine and Inspection Service (AQIS) has established guidelines for mandatory ballast water management which include a Ballast Water Decision Support System (DSS). The DSS assesses the risk associated with each vessel that enters Australian waters and determines whether it could be a carrier (or vector) of a foreign marine species of concern in its ballast water.

The International Maritime Organization recommends exchange of ballast water in the open ocean to reduce the risk of introducing marine species. Vessels carrying ballast water from 'high risk' areas are prohibited from discharging ballast water in Australian ports or coastal waters, unless they have re-ballasted at sea. However, this method is not fully effective at preventing the introduction of marine species and exchange at sea can be dangerous for ships. It is also expensive for the shipping industry, costing more than $23 million a year.

Researchers around the world are working to develop methods to improve the treatment of ballast water. However, the enormous volume of ballast water required for each journey (which can be up to 140 million litres per vessel) makes sterilisation extremely difficult.

In Australia, a team of CRC Reef researchers from James Cook University, and a consortium of Australian government and industry partners are working together as the Australian Ballast Water Treatment Consortium (ABWTC). The ABWTC has developed a pilot plant which is testing a combination of filtration, ultraviolet light and sonic disintegration to sterilise ballast water. The technology used in the plant has the potential to improve shipping safety by providing an alternative to the exchange of ballast water at sea. It will also provide better protection for Australian waters. Preventing future introductions of marine pests will save governments and industries around the world billions of dollars in costs to remove invasive species and prevent their spread.

Import of species for aquaculture and aquarium trade

A National Taskforce has established guidelines to ensure that fish and fish products imported for aquaculture are not likely to present a risk to coastal environments. AQIS also assesses the risk of importing live aquaculture and aquarium species.

Surveys

Given the high level of domestic and international shipping in Australia, there is a continuing threat of introducing exotic marine species. Therefore, it is crucial to continue to monitor ports using regular, standardised surveys. Ideally, surveys should be conducted every two or three years during different seasons as part of an ongoing early warning system.

Emergency response

Australia has an Emergency Marine Pest Plan to ensure there is a rapid response to invasions by exotic marine pests. In Queensland, the lead agency for marine pest emergencies is the Environment Protection Agency (EPA). When an introduced marine species is discovered, the EPA is alerted and assesses the extent of the infestation, and actions to be undertaken.

The response to the marine pest may include other Queensland agencies. The Consultative Committee on Introduced Marine Pests Emergencies (CCIMPE) is coordinated by the Australian Department of Agriculture, Fisheries and Forestry, and provides national coordination, advice and support to ensure a successful response.

Managing established marine pests

Development of a national plan to control the northern Pacific seastar *Asterias amurensis* was started in 1999. National control plans and local management plans will be developed for other established pests in the future.

Possible control measures for the northern Pacific seastar included chemical control, physical removal, biological control (introducing an exotic parasite or disease), biotechnology (e.g. genetically modifying the seastar to reduce its ability to reproduce) and education and awareness (ensuring that sources of food such as fish scraps are not available for the seastars).

Environmental management may also help to limit the spread and numbers of introduced marine pests because high pest densities, in some cases, may be a symptom of poor environmental quality. Remediation of degraded habitats and altered habitats may increase native biodiversity and perhaps also the resistance of native marine communities to invasion by marine pests. To mitigate the impacts of the northern Pacific seastar, or any introduced marine pests that have established large populations, a combination of methods will probably be needed.

Photo by CSIRO

Physical removal may be part of a control strategy for introduced pests such as the northern Pacific seastar.

Future research

Predicting spread of marine species

CRC Reef supports research on mathematical modelling of the hydrodynamics of ports and larval settlement patterns. This research is improving predictions of the potential movement of introduced marine pests.

Information from these studies and from port surveys conducted throughout tropical Australia is being used by port authorities to help manage their port environments as well as by state, national and international agencies to help develop standards to detect, monitor and manage introduced marine species.

Ballast water treatment

Research will continue into developing methods to treat ballast water and prevent the global translocation of introduced marine species. In September 2003, Australia hosted the First International Ballast Water Risk Assessment Workshop to develop ballast water risk assessment at the global level.

Other management options

Research will continue into developing better preventative measures, more efficient and cost-effective monitoring techniques such as genetic probes, and control options such as ecological and biological control.

Australia is also working with the International Maritime Organization to develop international instruments to prevent and manage the threat of introduced marine species. Australia will continue to play an important role in raising awareness of the issue.

More information

CSIRO website on introduced marine pests (formerly Centre for Research on Introduced Marine Pests) http://crimp.marine.csiro.au/

National Introduced Marine Pests Information System NIMPIS http://crimp.marine.csiro.au/nimpis/

Database of species found during Queensland port surveys http://www.coastal.crc.org.au/port_survey/

CRC Reef Research Centre

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