A REVIEW: BIOSECURITY RISKS POSED BY VESSELS AND MITIGATION OPTIONS

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Government of **Western Australia**
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EXECUTIVE SUMMARY

Vessels are recognised as one of the primary vectors involved in the introduction or translocation of non-indigenous marine organisms. Ballast water has generally been considered to be the primary vector of introduction and translocation for many non-indigenous marine organisms and has been the major focus of investigations concerned with marine invasion vectors.

Until relatively recently, the transport of non-indigenous marine organisms as biofouling on the external surfaces of a vessel and within internal seawater systems, has been given less consideration. However a number of recent studies, particularly in the southern hemisphere, suggest that biofouling may be the single most important vector in the introduction or translocation of non-indigenous marine organisms. Around 250 non-indigenous marine species have been identified in Australia, of which more than 75 per cent have been introduced through biofouling rather than in ballast water.

Open-ocean ballast water exchange is currently considered to be the best compromise in terms of efficacy, environmental safety and economic practicality for commercial ships to manage the potential risk of non-indigenous organisms being transported in ballast water. Open-ocean exchange represents a temporary solution until technology for managing ballast water is available, approved by governments and implemented by industry. Once ballast water has been loaded on board a ship, the ideal mechanism for preventing subsequent introductions of non-indigenous organisms is to treat the ballast water in such a manner that any organisms are killed prior to the discharge of ballast water.

In recognition that the uncontrolled discharge of ballast water and sediment has led to the transfer of non-indigenous aquatic organisms, ballast water discharge is increasingly subject to national (e.g. the United States' *National Invasive Species Act 1996*; Ballast Water Control and Management Regulations under the *Canada Shipping Act 2001*; New Zealand's Import Health Standard for Ballast Water from all Countries under the *Biosecurity Act 1993*) and international legislation (e.g. the International Convention for the Control and Management of Ships' Ballast Water and Sediments).

Despite the growing evidence that biofouling of vessels is an important pathway for the spread of non-indigenous organisms, the management of the associated biosecurity risks has proven challenging and the range of options for control is currently limited. The application of antifouling coatings to vessels' hulls is the most widely-used and effective measure to control biofouling. The issue of biofouling on international vessels has now been included on the work program of the International Maritime Organization (IMO). At the 56th session of the IMO's Marine Environment Protection Committee in July 2007, the Committee approved a new high-priority work item for its Sub-Committee on Bulk Liquids and Gases (BLG) on 'Development of international measures for minimising the translocation of invasive aquatic species through biofouling of ships'.

SECTION 1 – INTRODUCTION

Non-indigenous marine organisms (i.e. plants, animals, pathogens and diseases) have been identified as one of the greatest threats to the native biodiversity and ecosystem health of the world's oceans—after land-based sources of pollution, over-exploitation of natural resources and physical alteration/destruction of coastal and marine habitats (Raaymakers 2002).

Non-indigenous organisms may be introduced[1] or translocated[2] by a variety of anthropogenic and natural vectors[3], including ballast water from commercial (trading) shipping[4]; biofouling on the hulls and in the internal seawater systems of vessels; on fishing gear and aquaculture equipment (e.g. ropes, buoys, racks, baskets, settlement and grow-out lines, shellfish trays, and including vessels) and structures (e.g. fish cages, pontoons); ornamental (aquarium) imports; transfer of live, frozen and dried food products (e.g. for use as bait or aquaculture feed); as well as marine debris and ocean currents.

On a global scale, there is a clear pattern linking the introductions of non-indigenous marine organisms to the growth in the maritime trade and changes in shipping activities (Carlton 1985; Carlton and Geller 1993; Ruiz *et al.* 1997), which has occurred since humans began exploring the oceans (URS Australia Pty Ltd 2004; Hewitt *et al.* 2004; Hewitt and Campbell 2008 and references therein). The focus of this Occasional Publication is on the biosecurity risks presented by ballast water and biofouling, and the currently available mitigation options.

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[1] The transfer of an organism (or its propagules) into a region beyond its native range directly or indirectly assisted by human activity, intentionally or otherwise.

[2] Any deliberate or unintentional transfer of an organism (or its propagules) between disjunct sites.

[3] The physical means, agent or mechanism, which facilitates the transfer of an organism (or its propagules) from one place to another.

[4] These represent the majority of the world's fleet, and include, chemical tankers, container ships, crude oil carriers, gas carriers, dry bulk carriers, general cargo ships, livestock carriers, product tankers, vehicle carriers and 'roll-on roll-off' ferries and cargo ships.

SECTION 2 – BALLAST WATER AND SEDIMENTS

2.1 The Ballast Water and Sediment Biosecurity Risk

Ballast water is water (including the suspended matter [e.g. planktonic organisms] in the water and sediments settled out of the water) taken on board vessels, primarily commercial (trading) shipping[5], to achieve the required safe and efficient operating conditions during a voyage (or portion of a voyage). Most ballast water is taken on board in coastal and estuarine areas and tends to contain high levels of suspended sediments. Sediment frequently accumulates on the bottom and horizontal surfaces in ballast tanks. This sediment may include settled mud (silt and clay) from harbour, port, coastal and estuarine areas, detrital and other flocculent material ubiquitous in all shelf-waters, scale (rusted metal shedding off tank walls) and cargo residue. Sediment is typically removed every three to five years when a vessel is undergoing special survey or refit work in a dry-dock.

Ballasting fulfils a number of functions, including: reducing stresses on the hull of a ship, providing for transverse stability, aiding in propulsion by controlling the submergence of the propeller, aiding in maneuverability by submerging the rudder and reducing the amount of exposed hull surface (freeboard or windage) and compensating for weight loss from fuel and water consumption. The amount of water taken on board is dependent on the type of ship and the amount of cargo on board. Typically, a ship will take on ballast water into its ballast tanks from the surrounding waters when cargo is unloaded in one port (the source or donor port), and will usually discharge this ballast water, together with any organisms surviving the voyage, at or near subsequent ports of call (the recipient ports) when more cargo is loaded.

Shipping moves over 95 per cent of Australia's commodities (Australian State of the Environment Committee 2001) and, in so doing, transfers enormous quantities of ballast water. The International Maritime Organisation (IMO) estimates that there are approximately 10 - 12 billion tonnes of water moved around the world as ballast each year. In 2001, an estimated 150 million tonnes of ballast water was discharged into Australian coastal waters from international vessels and a further 34 million from domestic vessels (Australian State of the Environment Committee 2001). Commercial trading ports can therefore receive relatively large volumes of ballast water, originating from source regions throughout the world.

Each day there is an estimated 10,000 organisms being moved between various regions around the world in ballast water tanks (Knight *et al.* 2007). Organisms, ranging in size from viruses and bacteria[6] to fish living in the surrounding water, may be taken on board with ballast water.[7] As a single ballast tank can contain hundreds of species, a taxonomically diverse community of organisms is thereby unintentionally entrained and transported within the ballast tanks. For example, a survey of planktonic organisms in the ballast water of 159 cargo ships from Japanese ports recorded 367 distinctly identifiable species (Carlton and Geller 1993).

In 2006, over 123.4 million tonnes of ballast water were discharged from 4,081 vessels into Western Australia, the majority at the Port of Dampier (McDonald 2008). Approximately 95

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[5] Tankers and bulk carriers account for about 76 per cent (37 per cent oil tankers and 39 per cent bulk carriers) of the total volume of ballast water discharged from ships in international trade; general cargo and container vessels comprise a major part of the remaining 24 per cent (Endresen *et al.* 2004).

[6] Ballast water is also capable of transporting viral and bacterial pathogens, including for example, the bacteria that cause cholera.

[7] Concentrations of organisms per litre of ballast water are in the order of 10^0-10^2 zooplankton, 10^3-10^6 phytoplankton, 10^8-10^9 bacteria, and 10^9-10^{10} viruses (see references in Ruiz and Reid 2007).

per cent of the ballast water discharged was from international sources and just over five per cent from domestic sources. When scaled to the volume of ballast discharged within Western Australia, the cumulative number of organisms and the diversity of species delivered by this mechanism are therefore potentially large.

The movement of ballast water is considered to be one of the major transfer mechanisms for non-indigenous organisms to both marine and freshwater systems around the world (Carlton 1985, 1988; Hayes and Sliwa 2003; Drake and Lodge 2004). A subset of these non-indigenous organisms, when they are discharged into waters with appropriate environmental conditions, will be able to establish self-sustaining populations outside their historical native range and become invasive, potentially causing millions of dollars of costs to industry and natural resources.

Well-documented examples include the introduction of the comb jelly (*Mnemiopsis leidyi*) into the Black Sea and the Sea of Azov which changed the pelagic food chain, decimating local fish stocks and contributing to the collapse of the anchovy fisheries valued at $US 250 million (NIMPIS 2002); and the zebra mussel (*Dreissena polymorpha*) on the Eastern Seaboard of North America which has infested over 40 per cent of internal waterways, with control measures estimated to cost $US 100 million annually (Pimentel *et al.* 2000). An estimated 20 per cent of non-indigenous marine species in Port Phillip Bay, Victoria, have been introduced through ballast water discharge (Thresher *et al.* 1999; Bax *et al.* 2003; Hewitt *et al.* 2004).

As ships travel faster and passage durations consequently decrease, the survival rates of organisms in ballast tanks have increased, further contributing to the potential for incursions. Factors influencing the level of risk associated with the discharge of ballast water (McGee *et al.* 2006; Gollasch and Leppäkoski 2007; McDonald 2008) include:

- Source (or origin) of the discharged ballast water.
- Volume of ballast water discharged.
- Number of ship visits (i.e. frequency of ballast water discharges). Frequent ship visits generally result in a higher risk that these ships may discharge non-indigenous organisms to a favourable matching environmental 'window' at the recipient region.
- Voyage duration (i.e. storage time in ballast tanks). Scientific studies have shown that numbers of organisms in ballast water decline in time, with the greatest decrease occurring during the first 3 days of the voyage and few living individuals remaining after 10 days (Gollasch and Leppäkoski 2007). As ships have become faster, the likelihood that organisms in ballast water would survive the journey has thus increased.
- Environmental conditions in the recipient region (e.g. pollution, eutrophication, outflows of cooling water).
- Environmental match of source and recipient region (i.e. source and recipient locations in the same bioregion or within similar climatic zones). In general, a large number of potential source regions with similar environmental conditions represent a higher risk scenario than recipient regions with few shipping connections and dissimilar environmental conditions.

2.2 Measures to Mitigate the Biosecurity Risks Associated with Ballast Water

There are three stages in a ship's voyage where measures to mitigate the risk associated with ballast water can be implemented:

1. *On or before departure:* Management options are based on preventing or minimising the intake of organisms during the loading of ballast water at the source region, also taking into account the ballast requirements of safe ship operations and the locations and times of ballasting. Measures include avoiding uptake in areas with outbreaks, infestations or known populations of non-indigenous organisms; areas with current phytoplankton blooms; areas of sewage discharge; areas where tidal flushing is known to be poor; and areas where sediments have been disturbed, such as near dredging operations or where propellers may stir up sediment in shallow water.
2. *En-route*: Management options are based on the removal of viable organisms, either by open-ocean ballast water exchange or ballast water treatment, prior to discharge of ballast water in the recipient region.
3. *On arrival:* Management options are aimed at preventing the discharge of non-indigenous organisms that could survive in the receiving environment. If a ship arrives in a region intending to discharge ballast water but without having performed satisfactory ballast management procedures, there are two options for managing ballast water on arrival: transfer of ballast ashore for treatment at shore-based facilities if these exist, or retention and management of the ballast water on board the ship. Alternatively, a ship may be required to leave port and discharge or exchange ballast water at sea in an area considered safe and environmentally acceptable before returning to take on cargo.

At this time, open-ocean ballast water exchange is considered to be the best compromise in terms of efficacy, environmental safety and economic practicality for commercial ships to manage the potential risk of non-indigenous organisms being transported in ballast water. There are two major biological and ecological assumptions underpinning open-ocean ballast water exchange:

1. It is assumed that the probability of reciprocal introductions is reduced because of the differences between the biological conditions (including salinity) of the source waters and the open-ocean waters into which ballast water is discharged. Coastal and estuarine non-indigenous organisms discharged during an open-ocean ballast water exchange are presumed unlikely to survive in ocean waters. Similarly, oceanic organisms taken on during an open-ocean exchange and later discharged into coastal or estuarine waters are presumed less likely to survive in these environments. While some concern has been raised about open-ocean water entering coastal and estuarine ecosystems, it is generally considered that the volumes involved are typically minor compared to the overall volume and flushing characteristics of these areas.
2. The transport of viable released organisms back into coastal and estuarine waters from open-ocean by ocean currents is considered to be extremely unlikely.

There are two basic methods by which ballast water exchange may be undertaken, with the aim being that ships exchange at least 95 per cent of their ballast water taken on in coastal and estuarine areas for open-ocean water:

1. *Empty-refill or sequential exchange (de-ballasting/re-ballasting):* Ballast water taken on in coastal and estuarine areas is pumped out until the tank is empty (or as close to 100 per cent empty as is safe to do so) and the tank is then refilled with surface open-ocean water. This

method has the potential to remove 100 per cent of original water with only one volume of exchange, although it may be less in poorly designed tanks with 'dead spots', where water fails to circulate sufficiently despite efforts to flush the tanks (Clarke 2007; Eames *et al.* 2008).

2. *Flow-through or continuous exchange (flushing):* Ballast water taken on in coastal and estuarine areas is flushed out by continuously pumping surface open-ocean water into the tank, allowing water to exit through overflow or other arrangements to achieve three volume exchanges (i.e. a minimum of 300 per cent of each tank's full capacity must be pumped into each tank). The biological efficacy of this method is not proven to be equivalent to 95 per cent volumetric exchange but it is 'accepted' as being equivalent (Eames *et al.* 2008). This is the most common method used in Australia (Australian Ship Owners Association cited in Dunstan and Bax 2008).

Ballast water exchange as a ballast water management practice is available to the majority of commercial ships. With slight adjustments to operating procedures, exchange can be implemented without costly retrofits or expensive technology installations as ships are already equipped with the required ballast tanks and pumps to enable ballast water to be pumped in and out for stability and safety reasons.

However, there are some operational constraints associated with ballast water exchange. Proper exchange can take many hours to complete and may not be possible under some circumstances - for example, short voyage passage times or bad weather may not permit a complete change of ballast water by either method. In addition, the effectiveness of ballast water exchange in minimising the risk of introductions of non-indigenous organisms may be limited by vessel design.

Most ballast pumping systems and tanks are designed to remove as much water and sediment as practicable, but they cannot remove all ballast and associated organisms and pathogens, thus any organisms and pathogens remaining inside the ballast tanks may be discharged at some other time.

Although there is general consensus that ballast water exchange reduces the supply of non-indigenous organisms delivered to recipient coastal and estuarine areas, and thereby reduces the risk of invasion, the exact magnitude of this reduction is poorly resolved using either theoretical or empirical measures (e.g. Endresen *et al.* 2004; McCollin *et al.* 2007; Taylor *et al.* 2007; Dunstan and Bax 2008; Eames *et al.* 2008). Ruiz and Reid (2007) report that the process of ballast water exchange, whether 100 per cent empty-refill or 300 per cent flow-through, can be effective at replacing coastal ballast water with open-ocean water (88 – 99 per cent replacement of original water) and coastal planktonic organisms (80 – 95 per cent reduction in concentration) across ship types when conducted according to guidelines. The use of ballast water exchange has nevertheless significantly reduced the discharge of coastal organisms in ballast to the Great Lakes, Chesapeake Bay and other United States estuaries and the associated risk of invasions (Ruiz and Reid 2007).

Open-ocean exchange of ballast water is widely considered to represent a temporary solution until technology for managing ballast water is available, approved by governments and implemented by industry. Once ballast water has been loaded on-board a ship, the ideal mechanism for preventing subsequent introductions of non-indigenous organisms is to treat the ballast water so that any organisms are killed prior to the discharge of ballast water. Treatment of ballast water can occur during uptake, discharge or both uptake and discharge, and depending on the system there may be a minimum ballast water tank residence time to complete the treatment process.

There are currently about 30 treatment systems being developed around the world (GloBallast Programme 2000 - 2008; see also Hillman *et al.* 2004). Options being considered include mechanical treatment methods (e.g. filtration and separation), physical treatment methods (e.g. sterilisation by ozone, ultra-violet light, electric currents and heat treatment), chemical treatment methods (e.g. biocides) and various combinations of these methods. All of these methods require significant research effort, including scaling the various technologies to deal effectively with the quantities of ballast water carried by large ships (e.g. about 60,000 tonnes of ballast water on a 200,000 deadweight tonnes [DWT] bulk carrier).

In addition, any treatment method that is developed will need to meet a number of criteria, including safety of the ships' crew, cost and ease of operating the treatment system, the effectiveness of the treatment at removing target organisms, and the risks that the treatment may pose to the environment. Even when such systems do become available, there will still be the issue of retro-fitting the systems to the existing fleet, so it is likely to be several years before these technologies are widely used. In the interim, ballast water exchange is viewed broadly as a stop-gap measure that is immediately available for use on most ships and that will likely be in use for the next few years at least, being gradually phased out by the world's fleet as more effective technology-based methods become available.

2.3 International and National Initiatives to Manage the Risks Associated with Ballast Water

In recognition that the uncontrolled discharge of ballast water and sediment has led to the transfer of non-indigenous aquatic organisms, ballast water discharge is increasingly subject to national (e.g. United States *National Invasive Species Act 1996*; ballast water control and management regulations under the *Canada Shipping Act 2001*; New Zealand's Import Health Standard for Ballast Water from all countries under the *Biosecurity Act 1993*) and international legislation (e.g. the International Convention for the Control and Management of Ships' Ballast Water and Sediments).

In February 2004, the United Nation's International Maritime Organisation (IMO) adopted the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (the Ballast Water Management Convention). Signatories to the Ballast Water Management Convention agree to take measures that will help prevent, minimise and ultimately try to eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments. The Ballast Water Management Convention provides a comprehensive suite of obligations to signatory parties once the convention enters into force, with a number of guidelines supporting implementation.

The Ballast Water Management Convention will enter into force one year after its ratification by at least 30 parties to the IMO, constituting at least 35 per cent of the gross tonnage of the world's merchant shipping. As of 30 June 2008, 14 countries had ratified the Ballast Water Management Convention, representing 3.55 per cent of the world's fleet by tonnage. Australia signed the Ballast Water Management Convention, subject to ratification, on 27 May 2005 and is obliged to refrain from acts that would defeat the object and purpose of the Convention. Australia is currently progressing with the ratification of the Ballast Water Management Convention.

The Ballast Water Management Convention requires ships to exchange ballast water to a standard efficiency of 95 per cent by volume, as do most of the various national requirements (Ballast Water Exchange Standard). The Ballast Water Management Convention requires that all ships' undertaking ballast water exchange, should, wherever possible, conduct ballast water exchange at least 200 nautical miles from the nearest land and in water at least 200 m deep.

In cases where a ship is unable to conduct ballast water exchange in accordance with this requirement in the Ballast Water Management Convention, exchange is required to be conducted as far as possible from the nearest land and at least 50 nautical miles from the nearest land and in water at least 200 m in depth. When these requirements cannot be met, areas may be designated, taking into account environmental and economic factors, where ships can conduct ballast water exchange. However a ship is not required to deviate from its intended voyage, or delay the voyage, in order to comply with this requirement.

Ships also have an option of managing ballast water to the Ballast Water Performance Standard, which requires ships conducting ballast water management to discharge less than 10 viable organisms greater than or equal to 50 µm (microns) in size per m^3 of water and less than 10 viable organisms less than 50 µm but greater than 10 µm in size per millilitre of water.[8] In addition, the Ballast Water Performance Standard sets limits on the discharge of several disease-causing pathogens, including cholera, *Escherichia coli* and intestinal Enterococci. The specific requirements for ballast water management and the dates by which ships will need to meet the Ballast Water Exchange Standard and the Water Ballast Water Performance Standard are dependent on when the ship was built and its ballast water capacity, subject to the Ballast Water Management Convention coming into force.

On 1 July 2001, Australia introduced mandatory ballast water requirements for all international ships arriving in Australia from overseas. The Australian Quarantine and Inspection Service (AQIS) administers these requirements under the Commonwealth's *Quarantine Act 1908* (Australian Quarantine and Inspection Service 2008). Australia's requirements are consistent with the IMO's Ballast Water Management Convention, with some practical refinements not identified in the IMO Guidelines.

All internationally plying vessels intending to discharge ballast water anywhere inside Australia's territorial sea are required to manage their ballast water in accordance with the mandatory ballast water management requirements. The discharge of ballast water that has not been managed in accordance with the requirements is prohibited anywhere inside Australia's territorial seas (12 nautical miles). All salt water from ports or coastal waters outside Australia's territorial sea are considered to present a high risk of introducing exotic marine pests into Australian waters.

Masters of vessels may elect to use any of a number of ballast water management options approved by AQIS, including non-discharge of high risk ballast water, tank-to-tank transfer within the ship and full ballast water exchange at sea by an approved method to achieve 95 per cent (or better) volumetric exchange of high risk ballast water. Ballast water exchange must be conducted outside Australia's territorial seas (12 nautical miles), and, where possible, as far as possible from any land mass in waters at least 200 m deep. Any ballast water that has been exchanged at sea by an approved method is considered to be acceptable for discharge into Australian ports or waters.

All vessels arriving in Australia from international waters are required to submit a *Quarantine Pre-Arrival Report* (QPAR) to AQIS. The QPAR requires vessel masters to declare whether or not they have complied with Australia's mandatory ballast water management requirements. Masters must also complete the *AQIS Ballast Water Management Summary* which summarises the real-time records of ballast water management conducted at-sea, detailing the ballast water uptake ports, ocean exchange and intended Australian discharge locations.

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[8] To provide some context on the number of organisms this would allow, large ships may carry over 60,000 m^3 of ballast water. Under the Ballast Water Exchange Standard, this means that a ship discharging that amount of ballast water could legally discharge up to 600,000 organisms measuring more than 50 µm and 60 billion organisms measuring less than 50 µm. There has been some discussion in relation to adequacy of the Ballast Water Performance Standards (e.g. California Advisory Panel on Ballast Water Performance Standards 2005; Falkner *et al.* 2006).

AQIS officers conduct on-board ballast water verification inspections using the QPAR, the *AQIS Ballast Water Management Summary* and the vessel's deck, engineering and ballast water management logs to ensure compliance with Australia's ballast water management requirements. No ballast water may be discharged from internationally trading vessels in Australian waters without the written permission of AQIS.

Victoria is currently the only state that has in place requirements for the management of Australian-sourced ballast water. These are managed by the Victorian State Government's Environment Protection Authority under the State *Environment Protection (Ships' Ballast Water) Regulations 2006* which entered into force on 1 July 2006.

Under the 'National System for the Prevention and Management of Marine Pest Incursions', the Australian Government is responsible, through legislation, for ensuring that vessels that may discharge internationally-sourced ballast water are subject to agreed measures to minimise the risk of introducing agreed pests of concern through this ballast water for the duration of their voyage in Australia. The Australian states' and the Northern Territory, through legislation, are responsible for ensuring that vessels that may discharge ballast water taken up within Australia are subject to agreed measures to minimise the risk of translocating agreed pests of concern through this ballast water.

An independent review of Australia's Quarantine and Biosecurity Arrangements undertaken in 2008 has recommended that the Commonwealth Government should take responsibility for managing the biosecurity risks associated with international and domestic-sourced ballast water (Beale *et al.* 2008). It is considered that this would simplify the legislative and administrative arrangements and ensure that a comprehensive system for ballast water management is implemented. The Australian Government has agreed-in-principle to this recommendation with the aim of achieving agreement on a new national system by the end of 2009 (Australian Government 2008).

The Australian Government has agreed to drafting priority for ballast water legislation (the Australian Ballast Water Management Bill and Ballast Water Management Levy Bill) during the autumn 2008 sitting of Parliament, with a view to its introduction to Parliament later in the year. It is proposed that the target implementation date for the ballast water management arrangements will be tied to the availability of the Commonwealth legislation.

SECTION 3 – BIOFOULING

3.1 The Biofouling Biosecurity Risk

Biofouling is the growth of organisms on submerged surfaces, including bacterial, cyanobacterial and diatom biofilms; filamentous green algae and turfing red and brown algae; sessile organisms such as sponges, tube-building polychaetes (worms), bryozoans, bivalve molluscs and ascidians; and mobile benthic and epibenthic organisms such as polychaetes, nudibranchs (sea-slugs), amphipods, isopods, crabs, gastropod molluscs and even fish.[9]

Vessel biofouling includes all external wetted surfaces (e.g. sea chests, bilge keels, anode blocks, rudder pins, propellers, shaft protectors, echo sounder transducers and log probes) and internal surfaces (e.g. anchor wells, chain lockers, bilge spaces, fishing gear, bait lockers, cooling water intakes, strainers and pipe-work) where organisms can settle and survive.

The shipping and marine industries are heavily impacted by biofouling, and hull maintenance and the prevention of biofouling growth is an important consideration in commercial ship operation. Biofouling on a vessels' hull increases hull roughness, leading to increased friction between the hull and the water, which combined with the increased weight of fouling organisms, can lead to considerable increases in fuel consumption and engine wear and increased maintenance costs.[10]

Biofouling within a ship's heat exchangers and engine cooling system can restrict cooling flow in pipes, reducing heat transfer across heat exchangers and condensers, thereby reducing the efficiency of the system and increasing fuel consumption. The effects of such fouling include over-heated engines, increased engine 'revolutions per minute' (RPM), reduced air conditioning capacity, and acceleration of corrosion caused by fouling. Biofouling of submerged structures can cause increased drag, corrosion and infrastructure breakdown, decreasing production efficiency. Equipment (e.g. remotely operated vehicles [ROVs], seismic equipment, sea-floor sensing and geotechnical survey equipment) can also be affected by biofouling, increasing costs due to cleaning, maintenance and operational downtime.

Unlike ballast water, which is associated with the operational requirements of commercial (trading) ships, biofouling is an issue for virtually all classes of vessel, no matter how well designed and maintained they are (e.g. commercial fishing vessels, non-trading vessels[11], petroleum industry vessels, recreational craft) (e.g. Kinloch *et al.* 2003; URS Australia Pty Ltd 2004; URS Australia Pty Ltd 2007a, b). The overall biofouling risk profile of a vessel is generally influenced by the size, number and complexity of its niches, the vessel operating profile and the maintenance and cleaning practices implemented.

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[9] The colonisation of a surface is comprised of a series of phases: (1) biochemical conditioning; (2) primary biofouling comprising the build-up of bacteria, fungi, diatoms and protozoa to form slime, biofilm or 'micro fouling'; and (3) secondary fouling comprising the build-up (and subsequent senescence) of macrofoulers (e.g. green filamentous algae, bryozoans, barnacles and tube-worms) which provide the calcareous surfaces and micro-crevices that are attractive to other fouling species.

[10] A layer of algal slime 1 mm thick will increase hull friction by 80 per cent and cause a 15 per cent loss in ship speed, while a 5 per cent increase in fouling for a tanker weighing 250,000 DWT will increase fuel usage by 17 per cent (Evans *et al.* 2000). Vessel bottoms may gather up to 150 kg of fouling per square metre in six months, resulting in an increase in fuel consumption of up to 50 per cent when no antifouling coating is applied (see references in Löschau and Krätke 2005).

[11] Non-trading vessels include for example: dredges, barges and lighters, harbour services craft, ferries and water taxis, charter boats, cable ships, cruise ships, research vessels, fisheries patrol boats, seismic survey ships.

Biofouling is particularly an issue where the need for hulls that are clean and free of fouling (with the associated benefits of greater fuel efficiency and reduced engine wear) is not critical for maintaining operational efficiencies. Left unmanaged, biofouled vessels, structures or equipment can pose a biosecurity risk through the detachment and dispersal of viable material, and through spawning by adult organisms upon arrival in a recipient region. Simplistically, those vessels with the greatest levels of biofouling present the greatest biosecurity risk.

Certain vessels and structures are particularly prone to biofouling because of the activities they are involved in and therefore present a higher risk of transporting non-indigenous organisms. For example, dredges can be susceptible to biofouling and transfer of non-indigenous marine organisms because of long periods spent operating at low speed in high risk areas (e.g. shallow coastal and estuarine areas, commercial trading ports and harbours); long periods spent stationary in ports and anchorages between jobs; damage to antifouling coatings in some locations as a result of work activities; surfaces, components and fittings not treated with antifouling coatings due to operating and material requirements; and entrainment and capture of mud, sediments and biofouling in dredge equipment and ancillary fittings.

All vessel types have particular biofouling-prone features and niches, irrespective of the quality of their build, materials used, hull maintenance regime or antifouling coating. Niche areas are 'nooks and crannies' which are sheltered from the turbulence created by movement through the water. These are often areas which are difficult to clean and coat with antifouling, and where the settlement and survival of fouling organisms may be enhanced. These areas include sea-chests, bow thrusters and bow thruster tunnels, bilge keels, anodes, hull penetrations such as seawater intakes and discharges and grates, rudders and rudder stocks.

Niche areas are more likely to be vulnerable to biofouling than the main hull for a number of reasons (Australian Shipowners Association 2006; Coutts and Dodgshun 2007). Reduced thickness of antifouling coating on angular edges of grates and hull penetrations; the presence of hull protrusions which disrupt the flow of water over the hull, causing eddies which can result in premature polishing of antifouling coatings and removal from the hull; and antifouling coatings not polishing at the required rate in areas of static water (e.g. sea-chests, behind anodes) rendering the paint ineffective, are all factors making niche areas more vulnerable to biofouling. Eddies may also cause organisms to be deposited into niche areas, where there may be a greater likelihood of establishment due to reduced flows.

Coutts and Taylor (2004) identified three main groups of hull locations, where biofouling presents a significant problem:

1. Areas lacking antifouling coating (e.g. propellers);
2. Areas that have damaged antifouling coating. Mechanical damage to the antifouling coating can occur as a result of fender or berth impact, dropping and retrieval of anchors, collisions with debris. Operational impacts may also cause antifouling coating damage, for example when the hull makes contact with the seafloor causing abrasion and eventual removal of the coating; and
3. Areas with inactive or old antifouling paint such as the area beneath a vessel that cannot be painted with fresh antifouling during a dry-docking because of the position of docking support blocks.[12]

While ballast water has generally been considered to be the primary vector of introduction

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[12] For large ships, up to 15 – 20 per cent of a hull's flat bottom could remain unprotected as a result of lack of antifouling where support blocks were positioned (Taylor and Rigby 2000).

and translocation for many non-indigenous marine organisms and has been the major focus of investigations concerned with marine invasion vectors, transport of non-indigenous marine organisms as biofouling on vessel hulls, submerged structures and equipment has until recently been given less consideration. With the decline in the use of wooden-hulled trading ships, the faster speeds of modern ships and their shorter turn-around times in port as a consequence of containerisation and modern bulk handling equipment, and the development of more efficient, self-ablating antifouling coatings (e.g. organotin-based paints), fouling was widely assumed to no longer be a significant vector for non-indigenous marine organisms (e.g. URS Australia Pty Ltd 2004; URS Australia Pty Ltd 2007a). However a number of recent studies, particularly in the southern hemisphere, suggest that biofouling may be the single most important vector in the introduction or translocation of non-indigenous marine organisms (Coutts *et al.* 2003; Lewis *et al.* 2003; Minchin and Gollasch 2003; Coutts and Taylor 2004; Coutts and Dodgshun 2007; Drake and Lodge 2007).

Around 250 non-indigenous marine species have been identified in Australia, of which more than 75 per cent have been introduced through biofouling rather than in ballast water (Bax *et al.* 2003), including species such as the Northern Pacific seastar (*Asterias amurensis*), the seaweed *Undaria pinnatifida* and the European fanworm (*Sabella spallanzanii*).

A recent assessment of the relative contribution of vectors to the introduction and translocation of marine invasive species in Australia, reports that more species have life-history characteristic associated with biofouling (56 per cent global dataset; 69 per cent global dataset within an Australian context; 60 per cent Australian Port Survey dataset), while the second highest association was with ballast water (31 per cent global dataset; 22 per cent global dataset within an Australian context; 24 per cent Australian Port Survey dataset) (Hewitt and Campbell 2008).

Of the non-indigenous organisms reported from Port Phillip Bay, Victoria, some 78 per cent are considered to have been possible introductions though ship biofouling (Thresher *et al.* 1999; Hewitt *et al.* 2004). Some 70 per cent of New Zealand's non-indigenous marine organisms are thought to have been introduced through hull fouling (Cranfield *et al.* 1998), and of the 287 marine invasive invertebrate species in Hawaii, 212 (74 per cent) are considered to have been introduced through hull fouling and only 18 in ballast water (Godwin 2004).

The principal risk factors that determine biofouling accumulation (Ashton *et al.* 2006; URS Australia Pty Ltd 2007a) include:

- Vessel activity cycle including stationary periods and residence time(s) spent at lay-up, home port or assembly locations since last thorough cleaning, and movement patterns (cruising, working and transiting/towing speeds). Long stationary periods limit the self-ablating/self-polishing action of modern antifouling coatings, which increases the opportunity for thick biofilms to develop and for resistant taxa to colonise excessively leached or damaged coating areas.
- Vessel type including the number and range of niches that are difficult to access, clean or coat.
- Hull management practices including the timing and thoroughness of the cleaning operations and the antifouling regime, including suitability, age and condition of the antifouling coating.
- Voyage duration and route.
- Environmental conditions (salinity, temperature) in the source region which will determine the types of non-indigenous organisms likely to be present.

- Environmental match of source and recipient region (i.e. source and recipient locations in the same bioregion or within similar climatic zones). In general, the highest risks are when the source and recipient regions are within the same bioregion or climatic zone, increasing the likelihood that the fouling organisms will survive in the receiving habitats if similar environmental conditions exist.

3.2 Measures to Mitigate the Biosecurity Risks Associated with Biofouling

Despite the growing evidence that biofouling of vessels, structures and equipment is an important pathway for the spread of non-indigenous organisms, the management of the associated biosecurity risks has proven challenging and the range of options for control is currently limited.

The application of antifouling coating systems[13] to vessels' hulls is the most widely used and most effective measure to control biofouling. There are various different antifouling paint products on the market with different characteristics relating to the methods and speed of biocide release and effective paint life-span. Most antifouling coatings rely on one of the following methods of fouling control (Fillion in Takata *et al.* 2006; AMOG Consulting 2002; Thompson Clarke Shipping Pty Ltd *et al.* 2007; URS Australia Pty Ltd 2007b):

- *Biocide release coatings*: the presence of a biocide prevents biofouling attachment by continuously releasing a soluble biocide from the coating surface which either kills or deters the settling of larvae and spores attempting to attach to the surface. There are three main types:
    - Contact leaching (diffusion) coatings—the paint matrix is insoluble and the biocide leaches out of the coating through micro-channels created by the leaching process;
    - Soluble matrix coatings—the paint binder is soluble and the release of the freely associated biocide is facilitated by the binder dissolution; and
    - Self-polishing copolymer coatings—the paint binder is a copolymer that undergoes hydrolysis to facilitate the biocide ablation and release process.
- *Fouling release coatings (non-biocidal)*: silicone-based coatings which create an ultra-smooth, low surface energy 'non-stick' surface, where fouling organisms are either unable to attach or remain securely attached, such that fouling can be removed mechanically with brush, water jet and/or hydrodynamically at vessel speeds >15 knots and activity levels >70 per cent. Fouling release coatings do not contain active antifouling biocides.

Antifouling coating efficacy is dependent on matching the product to the particular activity profile of the vessel and the required service time between dry-dockings. For instance, fast moving vessels that spend minimal time in port are likely to adopt harder, slow-polishing, antifouling paints, whereas slow vessels are likely to adopt softer, faster-polishing paints. However, the recommended operational life-time of antifouling coatings is based on assessments designed to maintain or improve the vessel's performance, rather than to prevent establishment of particular fouling organisms.

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[13] "Antifouling coating systems" includes the antifouling paint and the underlying anticorrosion coatings, tie coats, primers etc. "Antifouling coating" refers to the fouling control coating containing active biocidal ingredients that has been applied to a hull (i.e. antifouling paint). Good biofouling management requires the correct selection of both the antifouling coating, with respect to vessel speed, activity, docking frequency, localized water flow etc., and antifouling coating system with respect to abrasion, capitation, inter-coat compatibility, substrate etc. (Australian Shipowners Association, communication to NIMPCG November 2008).

Paint efficacy is also dependent on the integrity of the coating. De-lamination, flaking and peeling of the antifouling paint will occur as a result of undercoat defects or when the antifouling coat has not been applied in direct accordance with the manufacturer's specifications or the hull surface has not been correctly prepared. Even small coating defects provide opportunity for organisms to settle, further compromising the integrity of the paint coating and encouraging the settlement of other organisms (Piola and Johnston 2008a, b).

Since the 1960s, tributyltin (TBT) has been the most effective biocide in antifouling coatings and in 2000 was used on more than 70 per cent of the world's ocean-going fleet (Evans *et al.* 2000; Yebra *et al.* 2004). However, environmental studies since the early 1980s have provided evidence that organotin compounds persist in water and in sediments, can affect the growth, morphology and reproduction of a range of non-target marine organisms and possibly enter the food-chain.

Environmental concerns over the potential impact of TBT-based paints, has led to regulatory measures around the world to prohibit the use of these antifouling coatings. The International Maritime Organisation (IMO) has taken a number of steps, including supporting the ban on the application of TBT on non-aluminium hulled vessels <25 m in length and eliminating the use of antifouling coatings with a leaching rate of more that 4 µg of TBT per square centimetre per day.

In October 2001, the IMO adopted the *International Convention on the Control of Harmful Antifouling Systems on Ships*[14] (the Harmful Antifouling Systems Convention), which prohibits the use of harmful organotins in antifouling paints used on ships and establishes a mechanism to prevent the potential future use of other harmful substances in antifouling systems. The Harmful Antifouling Systems Convention entered into force on 17 September 2008.[15]

The prohibition of the use of organotins in antifouling coatings is hampered by the lack of equivalent substitutes for TBT. In recent years, a variety of coatings have been developed to replace TBT-containing antifouling coatings, including copper-based paints and the use of synthetic biocides used in agriculture (e.g. Irgarol 1051, Thiram and Diuron). As a result of current and impending bans on the use of toxic antifouling coatings, many commercial vessel paint manufacturers are developing non-toxic antifouling coatings.

Alternatives to conventional biocide containing paints have to compete against highly efficient, long-lasting and well-priced paints and their applicability has to be proven in an appropriate way. The ban on harmful substances in antifouling coatings requires the development of new antifouling strategies with acceptable standards for use conditions and negligible adverse effects during occupational use, for both the users of the antifouling coatings and the environment (Löschau and Krätke 2005).[16]

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[14] The convention defines "antifouling systems" as "a coating, paint, surface treatment, surface or device that is used on a ship to control or prevent attachment of unwanted organisms".

[15] The Antifouling Systems Convention entered into force 12 months after 25 States representing 25 per cent of the world's merchant shipping tonnage had ratified it.

[16] The Australian Pesticides and Veterinary Medicines Authority (APVMA) is the national registration authority for agricultural and veterinary chemicals, including antifouling paints. Before an antifouling paint can enter the Australian market it must go through the APVMA's assessment process to ensure that it meets the required standards of safety and effectiveness. Standards Australia is the national standards writing body and has developed an extensive range of paint specifications and test methods for paint and two guideline standards for painting. With respect to antifouling paints, AS1580 Method 481.5 "Coatings-Durability Resistance to Fouling – Marine Underwater Paint Systems" is the only Standards Australia document specifically relating to antifouling paint. No national system of specifications or standards for antifouling paints currently exists in Australia and there is only one national test method (Thompson Clarke Shipping Pty Ltd *et al.* 2007).

The Harmful Antifouling Systems Convention has been negotiated to reduce and eliminate the use of organotin (specifically TBT) based antifouling paints and does not deal directly with the issue of non-indigenous organism transfers associated with vessel biofouling (and thus far nor does any other international convention). As new coatings are developed and vessels shift to different antifouling coatings with potentially lower efficacies, there are concerns that the risk posed by fouling as a transport mechanism for non-indigenous organisms may increase (AMOG Consulting 2002; Lewis *et al.* 2004; Sheppard 2004; Drake and Lodge 2007; Mineur *et al.* 2007).

The other major management option to control biofouling is physical removal of fouling material, either during maintenance periods when the vessels is dry-docked or through in-water cleaning. Removal of biofouling material in dry-dock usually coincides with the removal of old antifouling coatings and the reapplication of new coatings. Biosecurity risks posed by the use of dry-docking, slipways or haul-out facilities are likely to be less significant than in-water cleaning methods, and can be managed through the installation of barriers such as filters and containment tanks, to prevent the biofouling material from re-entering the environment.

Manual removal in-water by scraping or scrubbing of the hull can have important implications for the spread of non-indigenous marine organisms. Non-indigenous organisms dislodged from the hull may potentially survive and establish within the local area. Mature adults injured by the physical abrasion may be induced to release gametes and/or competent larvae into the surrounding environment. There is also some evidence that those areas where fouling is removed mechanically, without the reapplication of antifouling coating, are more susceptible to re-colonisation of fouling organisms which may increase the risk posed by that vessel (Floerl *et al.* 2005; Davidson *et al.* 2008; Hopkins and Forrest 2008).

The Australian and New Zealand Environment and Conservation Council's (ANZECC) *Code of Practice for Antifouling and In-Water Hull Cleaning and Maintenance* (the ANZECC Code of Practice), which was written primarily to mitigate the release of the TBT biocide in antifouling coatings into the marine environment, addresses in-water hull cleaning and maintenance. Under the ANZECC Code of Practice, no part of a vessel's hull treated with an antifoulant may be cleaned in Australian waters without the written permission of the administering authority. As in-water hull cleaning is currently prohibited, except under extraordinary circumstances, permission will not normally be granted.

The ANZECC Code of Practice also stipulates that all biological debris removed during in-water cleaning of the hull and niches areas is not allowed to enter into the water column or fall to the seafloor. These requirements apply in Australian waters and are applicable to all commercial vessels.

However, there may be situations where biosecurity risks resulting from in-water cleaning are less than those from unmanaged vessel fouling (Hopkins and Forrest 2008). For example, in the case of domestic vessel traffic and the management of internal borders, restrictions on in-water cleaning may act as a deterrent to vessel operators to clean their vessels, especially when faced with potentially expensive alternatives. In such circumstances, any unmanaged biosecurity risk may be exacerbated and exceed the risks presented by in-water cleaning, especially where best practices are adopted.

The National Introduced Marine Pests Coordination Group (NIMPCG) has recommended that a review of the ANZECC Code of Practice be undertaken to assess whether an alternative approach that promotes controlled in-water cleaning as part of a comprehensive strategy to minimise the presence of fouling on vessels is appropriate in those circumstances when it will lead to a risk reduction.

New technologies are being developed to enable biofouling to be removed while the vessel is in the water in a manner that does not allow the organisms to enter the environment (Aquenal Pty Ltd 2007). For example, in-water encapsulation techniques have been applied to fouled vessels, whereby the vessel is wrapped in plastic (encapsulated) *in situ*, creating anoxic conditions which are not conducive to the survival of organisms and chemical agents are added to the encapsulated water to accelerate mortality (Phipps *et al.* 2007).

Biofouling within a vessel's internal seawater systems has also been identified as a possible vector for non-indigenous organisms. To address this issue, regular inspection and treatment of internal seawater systems is required, including the installation of Marine Growth Prevention Systems (e.g. copper dosing or chlorination systems). A number of factors, including pipework configurations, components (including valves, joints and seals) and materials (e.g. rubber, plastics, polycarbonates, PVC, alloys and solders) and their compatibility or otherwise with the intended agent and method of application, as well as disposal of chemicals and materials, need to be considered in the selection and application of chemical cleaning agents.

3.3 International and National Initiatives to Manage the Risks Associated with Biofouling

While considerable attention has been directed to the management of ballast water, there currently exists no international legal instrument with which to manage biofouling. A number of existing legal mechanisms may be applicable in the context of coastal States' rights under international law, however existing mechanisms are insufficient to regulate all aspects of the biofouling risk to ensure comprehensive management of the issue and there is an urgent need for the development of a comprehensive international agreement to address this significant gap (Roberts and Tsamenyi 2008).

The issue of biofouling on international vessels has now been included on the work program of the IMO. At the 56th session of the IMO's Marine Environment Protection Committee in July 2007, the committee approved a new high priority work item for its Sub-Committee on Bulk Liquids and Gases (BLG) on "Development of international measures for minimising the translocation of invasive aquatic species through biofouling of ships". This came after consideration of a proposal by New Zealand, Australia, the United Kingdom, Friends of the Earth International and the World Conservation Union, urging IMO to address this issue. A target completion date of 2010 has been assigned.

The BLG has since given preliminary consideration to the issue and formed a correspondence group to review ongoing research, consider 'best practices' and potential future measures aimed at minimising the harmful effects of biofouling, consider the practicality and feasibility of various options for international measures for control and make a recommendation to the BLG. The BLG will also begin developing interim practical guidance for minimising the transfer of non-indigenous organisms through biofouling.

Note that while the IMO provides a comprehensive mechanism for regulating those international vessels registered under a Flag, a significant gap remains because the management of biofouling associated with the large fleet of vessels that falls outside of the IMO's mandate, including barges and associated support vessels, fishing vessels and recreational craft.

Since 1 October 2005, Australia has implemented voluntary guidelines for the management of biofouling on international vessels under 25 m in length. The Australian Quarantine and Inspection Service (AQIS) administers the guidelines. The guidelines focus on recreational vessels (sailing yachts, motor cruisers and motor sailers), apprehended vessels (particularly foreign fishing vessels and suspected illegal entrant vessels in northern Australian waters) and ships taken into Australian stewardship after being found abandoned and/or drifting at sea (i.e. Safety of Life at Sea [SOLAS] vessels).

The guidelines recommend, among other things, that the hull and underwater fittings should be cleaned within one month prior to arrival in Australia; or effective antifouling coatings should be no more than one-year old at the time of arrival in Australia if applied professionally in a boat-yard or six months if applied by the owner/operator; or that the vessel should be hauled out and cleaned within one week of arrival in Australia.

Under the 'National System for the Prevention and Management of Marine Pest Incursions', the Australian Government is responsible, through legislation, for ensuring that vessels entering Australia are subject to agreed measures to minimise the risk of introducing marine pests through biofouling. The Australian Government is currently developing the *Australian Biofouling Management Policy*. This sets out the overarching policy for the implementation of the Australian Biofouling Management Requirements for all arriving international vessels, to ensure that vessels entering Australia are subject to agreed measures to minimise the risk of introducing marine pests through biofouling.

The legislative framework will be established through amendments to the *Quarantine Act 1908*, specifically the *Quarantine Proclamation 1998* and the *Quarantine Regulations 2000*. It is currently proposed that the implementation of the biofouling management requirements will occur in 2009.

The Australian states and the Northern Territory are responsible for ensuring that vessels traveling between Australian locations are subject to agreed measures to minimise the risk of introducing marine pests through biofouling. There are currently no international treaty obligations or standards in relation to the management of biofouling, therefore a legislative approach by all jurisdictions is not required for biofouling as reflected in the National System.

Under the current legislative framework in WA, the Department of Fisheries is listed as an agency from which proponents for large-scale developments involving dredging and other marine construction work are required to seek advice in relation to the management of non-indigenous marine organisms. This is a requirement to meet the Proponents Environmental Management Commitments and the Environmental Conditions set by the Minister for the Environment and presented in Ministerial Statements following assessment of projects under Part IV of the *Environmental Protection Act 1986*.

Previously the Department has also negotiated resolutions to minimise the risk of introduction of non-indigenous marine organisms with owners/operators/agents of vessels which are identified to be biofouled and therefore in breach of Regulation 176 of the *Fish Resources and Management Regulations 1995*. Regulation 176 provides for the management of the translocation of live 'fish'[17] which are not endemic to the State or an area of the State.

In the future, it is envisaged that regulations under either the *Fish Resources Management Act 1994* or the recently passed *Biosecurity and Agriculture Management Act 2007* (BAM Act) may provide the legislative framework for the management of the risk of translocating marine pests through biofouling of vessels, structures and equipment moving into and within Western Australian waters.

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[17] Under the *Fish Resources Management Act 1994*, 'fish' is defined as an aquatic organism of any species (including eggs, spat, spawn, seeds, spores, fry, larva or other sources of reproduction or offspring of an aquatic organism), but excluding aquatic mammals, aquatic reptiles, aquatic birds, amphibians or pearl oysters.

National Biofouling Management Guidelines/Guidance Documents are being developed through the National Introduced Marine Pests Coordination Group (NIMPCG) for production and communication to the following sectors: Commercial fishing vessels; non-trading vessels; petroleum vessels; commercial shipping; aquaculture; and recreational vessels.

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