National Marine Science Plan: White Paper on Biosecurity and Marine Pests in Coastal Waters

1 Abstract

As an island nation, Australia clearly derives many social, cultural, environmental and economic benefits from its marine environment. The increasing global demand for maritime resources, increased global vessel movements and large scale factors such as climatic change all affect the likelihood of invasive marine pests entering Australia and threatening our marine environments and Australian lifestyle. While Australia has an internationally respected reputation in the area of marine biosecurity management, research in this area is severely under-resourced and under-funded. This document identifies four fundamental aspects of marine biosecurity and marine pest management as having significant knowledge gaps requiring investment into research and development (R&D). We also identify the critical need for an effective communication and information sharing network and an independent, scientifically focused advisory panel to act as a central overseer of marine biosecurity R&D in this country.

2 Background

One of the fundamental responsibilities of the Australian Government is to protect and enhance our national resources and values, whether they are economic, social, cultural or environmental in nature.

As an island nation, Australia clearly derives many social, cultural, environmental and economic benefits from its marine environment. The marine environment (not including commercial shipping) contributes $44 billion to the Australian economy, and by 2025 this contribution will increase to more than $100 billion per annum [1]. The Australian coast is home to some of the most unique and biodiverse hotspots on the planet, containing iconic treasures such as the Ningaloo and Great Barrier Reef systems, the Kimberley coast, and the Great Australian Bight.

The increasing global demand for maritime resources, increased global vessel movements and large scale factors such as climatic change all affect the likelihood of invasive marine pests entering Australia and threatening our marine environments and Australian lifestyle. These stresses will be cumulative and may be synergistic, making effective management a national concern. Marine biosecurity has a preparedness and response role to minimise the threats to Australia's maritime and coastal resources from marine pests and diseases.

There are currently 429 recognised introduced species in Australia, some of which have become significant marine pests. From the time the North Pacific seastar, *Asterias amurensis,* was first detected in Port Phillip Bay in 1995, the population of this voracious predator grew to an estimated 96 million within five years. Similarly, established populations of the large Japanese kelp, *Undaria pinnatifida,* discovered along the northern shores of Port Phillip Bay in 1996 have since spread extensively throughout the bay's southern shores. Further spread of these species along the open coast and into more pristine coastal embayments would significantly impact on the unique marine communities of Australia's southern coastline.

The likelihood of further introductions such as these is ever increasing as port development and international shipping traffic increases. For example, in 2012 there were 53,000 vessel visits to Western Australia alone, with each of these visits representing a potential marine biosecurity risk. There exists a significant disconnect between the risks and impacts posed by marine pest introductions and the levels of funding and resources allocated to the problem.

In Australia, marine biosecurity is a significant risk that is under-resourced, undervalued and overlooked [2]. A 2012 capability audit on national biosecurity research and development (R&D) found that full time effective (FTE) staff working in marine biosecurity R&D in Commonwealth and state/territory organisations (including CSIRO) was only 15.4 [3]. The same audit found that annual external funding for invasive marine species R&D in these organisations totalled less than $600 thousand nationally, and concluded the sector was "particularly vulnerable" as the funding sources and staff retainment were largely unstable.

Investing in a properly implemented and well-funded multi-layer national system of marine biosecurity R&D (involving both pre- and post-border programs) will ensure an effective biosecurity strategy that benefits all Australians. However, the size and location of Australian poses unique challenges to implementing effective marine biosecurity measures. Economically, we are heavily reliant on maritime transport, which increases the risk of invasive marine species arrivals. Geographically, Australia has 60,000 km of coastline, with territorial waters containing all five of the world's ocean temperature zones (polar, subpolar, temperate, subtropical and tropical), making development of a single uniform biosecurity strategy problematic. Finally, there is significant disparity across regional jurisdictions in the level of funding, resources and overall importance placed upon marine biosecurity.

A multi-tiered strategic and adaptable science and research program is critical to ensuring effective marine biosecurity for Australia. Foundation research should underpin our risk analysis and decision making capability, enabling preparedness and identification of biosecurity threats. Responsive research capability is also necessary for rapid response to immediate and unforseen threats as they emerge. Finally, long-term strategic R&D is vital to anticipating future and emerging biosecurity challenges. Importantly, all these R&D approaches must be centrally and independently coordinated, complementary and efficiently managed to be effective.

3 Relevance

Australia has an internationally respected reputation in the area of marine biosecurity R&D. We have an historically sound technical base from which to address marine biosecurity risks, arising from world renowned research programs such as those established at the now disbanded Centre for Research on Introduced Marine Pests (CRIMP)[1] and CRC Reef[2] [2]. Outputs of this work provide many direct and indirect benefits for a host of stakeholders and end-users, both domestically and abroad. For example, much of the Commonwealth and state/territory policy frameworks governing marine biosecurity and pest management are based upon science and research conducted in Australia.

As a nation, Australia is heavily reliant on shipping. In 2009 – 10, Australian exports by sea were valued at almost $179 billion, with 4,344 vessels making 25,162 visits to Australian ports from

[1] Centre for Research on Introduced Marine Pests: www.cmar.csiro.au/datacentre/refs/crimp_tech_reports.htm
[2] CRC Reef: http://crcreef.jcu.edu.au/discover/plantsanimals/introduced/index.html

outside the Exclusive Economic Zone (EEZ) [1]. Shipping is the primary vector for marine species introductions, via mechanisms such as biofouling and ballast water, and Australian research outputs and expertise form an integral foundation for risk assessment and regulatory frameworks managing biosecurity risks for this important vector both in this country [4-8] and overseas [9, 10].

Ever increasing port and coastal development means international vessel arrivals are increasing annually, and with them the likelihood of invasive pests and disease introductions. Marine pests can cause significant impact to port and vessel infrastructure (both operationally and economically), with ports also acting as 'stepping stones' for their spread into nearby high-valued areas (e.g. marine reserves). Australian research into the mechanisms driving species introductions in ports and harbours [11, 12] provides managers with tools and strategies to maintain our port environments, and this research needs to be stably supported.

There are examples from around the world where marine pests have severe economic impacts on aquaculture operations [13-15]. Global aquaculture currently accounts for nearly half the world's food fish consumption. In 2010, Australian aquaculture was valued at $870 million dollars (almost 40% of total fisheries value in 2010) [1]. In a time where food security is fundamental to social and political stability [1], Australian-based biosecurity and marine pest research is vital to ensure the protection and growth of this globally important resource into the future.

There is a strong history of stakeholder engagement and input in relation to marine biosecurity and pest management in Australia, through the development of national and international policy as well as the identification and facilitation of foundation science and research. For example, Commonwealth marine biosecurity strategies such as the *Proposed Australian Biofouling Management Requirements* [5] and the *National Priorities for Introduced Marine Pest Research and Development 2013-2023* [16] are based on inputs from a diverse range of stakeholders ranging from government agencies, the shipping industry, ports authorities, the oil and gas sector, consultancy and the marine science community. Cooperation is also demonstrated at the coal face of marine biosecurity management implementation between jurisdictional departments and stakeholder organisations [17].

In 2013, the international Institute of Marine Engineering, Science & Technology (IMarEST) established a Biofouling Management Expert Group (BMEG); an expert group aimed at providing a platform for knowledge exchange and technical expertise on the issue of marine biofouling, including biosecurity and marine pest management. Establishment of the BMEG was an outcome of the ANZPAC Workshop on Biofouling Management for Sustainable Shipping held in Melbourne in May 2013, and the Australian maritime sector is well represented with an Australian chair, committee membership, and group members from a range of maritime sectors including state government regulators, museums, the oil and gas industry and the commercial diving sector.

4 Science Needs, Gaps and Priorities

The Australian Marine Pest Sectoral Committee (MPSC – formerly National Marine Pest Coordination Group - NIMPCG) was formed in 2011 with an aim to develop, coordinate, implement and monitor national activities to address marine pest related biosecurity issues and provide leadership in the implementation of the National System for the Prevention and Management of Marine Pest Incursions[3] (hereafter referred to as The National System).

[3] The National System: www.marinepests.gov.au/national-system/Pages/default.aspx

In 2013, the MPSC released the *National Priorities for Introduced Marine Pest Research and Development 2013-2023* [16]. The document provides a reference for and prioritisation of biosecurity and marine pest research in Australia over the next 10 years to underpin The National System, and was developed in consultation with a wide range of research partners and stakeholders from the Australian marine science community (universities, cooperative research centres, Commonwealth and state research agencies, Australian Marine Science Association), industry sectors (shipping, ports, oil and gas, aquaculture) and community groups (Marine and Coastal Community Network, Coastcare, Conservation Council of Australia).

The document identifies four fundamental aspects of marine biosecurity and marine pest management as having significant knowledge gaps requiring investment into R&D: (1) vector management, (2) species and ecological information for management, (3) monitoring, evaluation and review, and (4) information, communication and education. Overall, a total of 33 priority areas for marine biosecurity and marine pest R&D in Australia are outlined. These priorities are ranked as LOW, MEDIUM and HIGH, with short (1-2 years), intermediate (2-5 years) and long (5-10 years) program durations. In an effort to provide an achievable R&D target that is matched to the realistic state of funding in this area, this white paper will only focus on the HIGH priority R&D needs over the next 10 years.

Irrespective of the science areas and priorities adopted for future research, the establishment of an overarching national network to coordinate R&D activities is paramount for the on-going success of marine biosecurity management in Australia. The scale and scope of marine biosecurity management required for Australia is large and diverse. A profound lack of funding opportunities in this area also means science and research must be targeted, complimentary and without overlap. This necessitates the need for an effective communication and information sharing network. Australia must establish an independent, scientifically focused advisory panel to act as a central overseer of marine biosecurity R&D in this country. Such a group should facilitate the networking of Australia's varied (and often fragmented) marine biosecurity scientific community, prioritise and track research goals, and direct the allocation of limited funding and resources where it can be used most effectively.

4.1 Vector management

To have an effective marine biosecurity management framework, Australia must first understand and manage the transport vectors responsible for the arrival and spread of invasive marine species. This should include analysis frameworks to identify and prioritise different vector risks, and the research and development of tools and technologies to reduce said risks.

SCIENCE GAPS & CHALLENGES: Risks associated with some vectors, such as aquarium trade imports, are poorly understood and managed. Even the relatively well understood vectors, such as shipping, have challenging sub-vectors such as niche area biofouling, which to this day lack effective management solutions. This is a critical point of vulnerability requiring urgent attention. Innovative R&D is vital to understanding and managing mechanisms contributing marine pest introductions from the often unique Australian perspective.

SCIENCE PRIORITIES: Vessel biofouling is undoubtedly the key vector for introducing invasive marine species. Despite this, vessel management practices to reduce this biofouling risk are still in their infancy. Furthermore, the methods of treating biofouling to reduce any risk remain poorly realised. In-water cleaning has proven to be an effective process for reducing the biofouling risk

associated with invasive marine species in other parts of the world. However, Australian vessel operators and biosecurity managers have few in-water treatment options that are both effective and compliant with strict Commonwealth and state in-water cleaning regulations. R&D funding must be directed toward the education of vessel operators to the risk that biofouling poses and the creation of tools and technologies that provide a greater range of effective treatment options for regulators and industry.

HIGH PRIORITY R&D	SCOPE
1. Tools for assessment, identification of risk and treatment of biofouling in vessel niche areas	5-10 yrs
2. Develop Australian-compliant in-water cleaning technologies for all vessel types	5 yrs
3. Understand risks and risk taxa associated with aquarium trade	2 yrs
4. Test risk assessment process underpinning Australia's Ballast Water Management framework	5 yrs

NATIONAL BENEFIT: Once a new marine pest population becomes established, management options become increasingly limited, are often prohibitively expensive and have minimal chance of success. Through improved vector management, Australia can significantly reduce marine biosecurity risks at a stage early enough in the translocation process that minimises the risk of arrival and therefore ensures the most optimal use of limited available resources.

4.2 Species and ecological information for management

It is important to note that not all species introduced into a new area will exhibit pest tendencies. Furthermore, some species may exhibit pest characteristics in certain environments but not in others (e.g. urbanised ports vs. natural habitats). R&D on current listed species and ecological information for management must involve the identification and prioritisation of likely 'next pest' species relevant to Australia. For effective prevention of marine pest arrivals, emergency preparedness and response to new incursions and management and control of established marine pests populations, Australia must first understand the biology, ecology and impacts of current listed invasive species in the context of Australia's often unique marine environment. Such understanding will then inform best practice for the most appropriate risk management approaches for effective marine biosecurity.

SCIENCE GAPS & CHALLENGES: Identifying 'next pest' species is a difficult process. Australia's current trigger list of potential marine pest species is outdated, and largely based on overseas experience rather than a sound understanding of the ecology and behaviours of potential pest species under often unique Australian conditions, affecting the predictive accuracy of risk management frameworks and undermining potential eradication efforts. Crucially, there is a lack of research into how the rapidly changing nature of Australian coastal environments (e.g. increased port and coastal urban development, climate change) is contributing to the establishment and spread of current and future pest species.

SCIENCE PRIORITIES: When Australian 'next pest' species are identified, it is vital that we have the facilities and expertise to develop modern molecular techniques for rapid and accurate species detection. Genomic tools can detect individual species in the marine environment, often at early life stages that are impossible to identify using traditional taxonomic techniques. A global decline in taxonomic expertise makes genomics particularly important for marine pest detection; however, significant research and testing is required to develop and validate genomic probes and markers that are robust under real-world conditions.

HIGH PRIORITY R&D	SCOPE
1. Develop improved methods for rapid detection of invasive marine species – including, but not limited to, molecular probes	2-5 yrs
2. Studies of biology/ecology of priority invasive marine species (reproduction, competition, life cycle)	5 yrs
3. Assess and quantify socio-economic impacts of invasive marine species	5 yrs
4. Test efficacy of options for eradication of marine pests	5 yrs

NATIONAL BENEFIT: Understanding the ecology of current and potential invasive marine pests and the species population response and impacts they may have on Australian marine ecosystems is essential for the effective prioritisation and allocation of limited management resources in this area.

4.3 Monitoring, evaluation and review

Effective surveillance and monitoring in marine systems can be costly, time consuming and challenging. Australia must ensure on-going R&D capability to continually improve the cost-effectiveness of marine pest detection and monitoring programs and techniques, develop a fundamental understanding of high-risk marine habitats and marine pests, and deliver continuous adaptive improvement to pest management strategies.

SCIENCE GAPS & CHALLENGES: The distribution and abundance of current introduced and future invasive marine species must be monitored, mapped and effectively communicated. Risk assessment frameworks must also be developed to differentiate and prioritise potential marine pest impacts in habitats of low importance versus those of high natural or economic values. R&D into new technologies (e.g. autonomous underwater vehicles, genomic analysers) and real-time data analysis is required to provide cost-effective and higher frequency marine pest surveillance for priority environments, while also increasing predictive detection capabilities.

SCIENCE PRIORITIES: On-going research is essential to catalogue and prioritise habitats and environments that are likely locations for initial incursions, or susceptible to harmful impacts from species introductions to optimise resource allocation. This should include reviewing the existing National Monitoring Network to identify habitat information gaps. Research into autonomous and remote surveillance techniques/platforms is vital to address time, cost and safety issues that currently prohibit cost-effective broad-scale surveillance (using conventional techniques). In addition, risk models that use vessel history to predict the probability of invasion at a particular Australian port may provide an automated and cost-effective framework for identifying potentially high risk vessels. High risk vessels would then be subject to greater attention, such as physical inspections and increased precautionary measures. While not removing the need for on-the-ground monitoring, this approach would provide a supplementary tool with which to prioritise limited resources. Such risk models require investment to create, but once in place can be executed at low cost. Finally, one of the major impediments to marine biosecurity programs worldwide is the increasing lack of taxonomic expertise available for species identification. Parataxonomic techniques appear as viable solutions to this problem, but require quantitative studies to determine their reliability and usefulness.

HIGH PRIORITY R&D	SCOPE
1. Revise the National Monitoring Network to be more cost-effective and adaptable ensuring uptake and implementation	2-5 yrs
2. Develop remote inspection tools to assess extent of vessel biofouling, in particular for niche areas	5 yrs
3. Develop risk models that predict the probability of invasion at particular Australian ports	2-5 yrs
3. Parataxonomic tools for rapid and robust identification of pest species to support monitoring	2 yrs
4. Assess risk-reduction achieved using diverse management strategies, incl. benefit-cost-trade-offs	2-5 yrs

NATIONAL BENEFIT: Rapid and accurate pest species identification and cost-effective detection and monitoring methods will ensure Australia protects the high-value marine resources it depends upon for economic and social well-being. This is particularly pertinent given the rapid increases in port development and international shipping traffic around Australia (increasing the threat of invasive marine species) and the simultaneous increased value being placed on marine environments (e.g. establishment of new marine reserves).

4.4 Information, communication and education

Accurate and up-to-date information is crucial to an effective national biosecurity management system. Australian R&D on biosecurity information, communication and education will ensure governments, industry and community stakeholders have access to robust, useable and current management and invasive marine species information.

SCIENCE GAPS & CHALLENGES: The scale and scope of marine biosecurity management required for Australia is large and diverse. A profound lack of funding opportunities in this area also means science and research must be targeted, complimentary and without overlap. This necessitates the need for an effective communication and information sharing network.

SCIENCE PRIORITIES: A centralised and integrated approach to Australian marine biosecurity R&D is required to identify gaps in capability and expertise, while coordinating research efforts is a way that minimises duplication of effort. The establishment of a research network, including not only academia but also industry, government and the private sector, is crucial to ensuring visibility and interaction between complimentary research areas and communication of research outcomes to end-users for evaluation and uptake.

HIGH PRIORITY R&D	SCOPE
1. Foster the establishment of researcher networks for marine biosecurity and pest research	5 yrs
2. Develop training and capability building initiatives in areas such as marine pest assessments	5 yrs
3. Understand sociological factors impacting the uptake of risk mitigation strategies by stakeholders	5 yrs

NATIONAL BENEFIT: Through development of a robust and multi-faceted communication network, Australia can ensure that marine biosecurity research and training remains relevant and up-to-date, thus maintaining our reputation as a world leader in this area. Importantly, effective education on the importance of marine biosecurity will ensure industry and community stakeholder buy-in and the adoption of best-practice approaches for biosecurity and marine pest management.

5 Perspective

Marine biosecurity is a holistic field encompassing education, species biology and ecology, vector and stakeholder management, and control/eradication programs. Marine biosecurity is also a global issue. The increasing global demand for maritime resources, increased international vessel movements and large scale factors such as climatic change all affect the likelihood of marine pests being translocated and introduced somewhere around the globe. These stresses will likely be cumulative and synergistic, making management a global concern. A strategic, consistent, scientific approach to protecting our marine environment from invasive marine pests is essential and should be at the heart of every country's marine biosecurity.

Australia's marine pest biosecurity system complies with its international rights and obligations, and we are signatory to a suite of treaties aimed at minimising the spread of invasive marine species, including the United Nations Convention on the Law of the Sea[4], the Convention on Biological Diversity[5] and the World Heritage Convention[6]. The Commonwealth has implemented mandatory Ballast Water Management Requirements [18] following the International Maritime Organisation (IMO) Ballast Water Convention[7] despite that fact that the Convention has yet to be ratified. Australia also meets national, state and territory obligations and laws, and follows the approaches of the broader national biosecurity system as outlined under the Intergovernmental Agreement on Biosecurity[8] (IGAB). However, it faces considerable challenges with our national marine biosecurity research and monitoring capabilities associated with an ageing work force and a declining skills and resource base.

To develop strategic science and management for many areas of marine biosecurity, organisations within Australia are working strategically with countries such as New Zealand and the United States (particularly California and Hawaii). Key issues being addressed include, in-water cleaning to reduce marine pest translocations, development of passive surveillance tools, evaluations of the risk and treatment of recreational yachts as vectors of marine pests, and examination of new surveillance tools such as remotely operated vehicles (ROVs) for pest surveillance.

While these international linkages are extremely positive and productive, there remains a need for a strategic independent, scientifically focused advisory panel to act as a central overseer of marine biosecurity R&D in this country. Having such a body to better position Australia within a global context would not only ensure Australia's needs are met, but also utilise skills, experience and resources globally

6 Realisation

6.1 Key infrastructure and capability requirements

In July 2012, a National Biosecurity Research and Development and Extension (NBRD&E) capability audit (hereafter referred to as 2012 audit) was conducted to better inform the NBRD&E framework of the IGAB [3]. This 2012 audit was spread across the sectors of animal health, plant health, invasive weed species, invasive animal species and invasive marine species. Responses were compiled from a range of agencies including government, university, and R&D corporations.

State and federal government represented the biggest providers of biosecurity policy, management and research accounting for 58% of the national capability. The 2012 audit identified a total of 818.3 full time equivalent (FTE) staff employed in biosecurity R&D, with the greatest proportion of FTE being in the plant and animal health sectors (649.5 FTE or 79%). Those involved in the marine sector represented only 1.88% (15.4 FTE) of the total national biosecurity capability. This is despite over 70% of Australia's territory lying in the marine realm and a coastline extending for 59,736 linear km. That 2012 FTE value equates to one FTE being responsible for conducting marine biosecurity science along 3,878 km of coastline. While few would disagree with the allocation of resources to protect our

[4] UNCLOS (1982): http://www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm
[5] Convention on Biological Diversity (1992): http://www.cbd.int/doc/legal/cbd-en.pdf
[6] World Heritage Convention (1972): http://whc.unesco.org/en/convention/
[7] IMO BWM Convention: http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-%28BWM%29.aspx
[8] IGAB: http://www.daff.gov.au/animal-plant-health/pihc/intergovernmental-agreement-on-biosecurity

terrestrial resources, it is likely many would agree that more resources are needed to protect our marine environments.

The need for greater national commitment to marine biosecurity resourcing is highlighted by statements from a growing number of sources:

> *"Marine Biosecurity is a significant risk which is poorly recognised….there is a mismatch between perceptions and the resources allocated"…. "The resources applied to managing marine biosecurity in Australia do not appear to match the magnitude of the risk and are fragmented between government agencies and authorities, commercial entities, environmental interests and research organisations."*
> *CSIRO Biosecurity Flagship - Marine Biosecurity Workshop July 2013: Summary Report* [2].

An assessment of the 2010 Fisheries Research and Development Corporation (FRDC) Research, Development and Extension (RD&E) capability [19] identified that Biosecurity and aquatic animal health is currently "inadequate" and requires an increase in the RD&E capacity in the immediate term (1 to 5 years).

> *"Nationally, Australia is well prepared for biosecurity incursions in terrestrial industries. But it is less clear that we are able to identify the risks and are ready to defend the health and security of aquatic animal and plant species and their dependent communities and users."*
> *Working Together: the National Fishing & Aquaculture RD&E Strategy 2010* [19].

A primary outcome from the 2010 (FRDC) strategy was that "…the Australian community derives optimal economic, environmental and social benefits from its fishery and aquaculture resources…" which aims to be achieved through supporting outcomes such as "…a **nationally coordinated approach to biosecurity** and aquatic animal health."

6.2 Funding and coordination requirements

Around the nation there are dedicated and talented staff working in marine biosecurity science. However, dwindling support and a lack of funding for marine biosecurity science puts the retainment of individuals with these skills and experience at risk.

A recent analysis of Australia's marine biosecurity capabilities [20] highlighted many areas of science previously identified in other reviews that are still of national concern and interest. These included:

- Marine pest surveys of boating marinas
- Methods to reduce costs associated with monitoring and surveillance
- Development of a more cost-effective user friendly national system monitoring program
- Harbour modelling for pest spawning dispersal to inform targeted monitoring
- Risk assessments of estuaries and high risk areas

The capability analysis found that only half of the government agencies responsible for marine pest management actually undertook their own research internally. Approximately 40% of jurisdictions identified that they outsourced science requirements due to a lack of in-house skills (including

specific skills or no staff), time restrictions, and/or the fact it was not in their agency mandate to do internal research.

Four jurisdictions highlighted that they do not do, or do not have the capacity to do, any marine biosecurity research whatsoever. We therefore reiterate the clear national need for a formal marine biosecurity science network to be established. Only through a coordinated and strategic approach can Australia hope to deliver on its regional and international obligations to "…prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species"[9]. Only by uniting jurisdictions will we have a robust and collaborative basis from which to support one another, pool skills and expertise and obtain resources commensurate with the increasing biosecurity risk and national need. A national group would also provide a central contact point to facilitate communication with international bodies tackling similar issues. National biosecurity is an inherently international problem, and free flowing communication between international parties is vital for effective management. Although Australia has much biosecurity expertise, the absence of a coordinated front is an impediment to sharing information at an international level. There needs to be a national repository of information and expertise to readily engage with international efforts.

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[9] Convention on Biological Diversity: http://www.cbd.int/doc/legal/cbd-en.pdf

8 References

1. OPSAG (2013) *Marine Nation 2025: Marine Science to Support Australia's Blue Economy*. Oceans Policy Science Advisory Group.
2. CSIRO (2013) *CSIRO Biosecurity Flagship - Marine Biosecurity Workshop July 2013: Summary Report*. CSIRO.
3. DAFF (2012) *National Biosecurity Research and Development Capability Audit. Intergovernmental Agreement on Biosecurity – Research, Development and Extension Working Group*. Department of Agriculture, Fisheries and Forestry.
4. DAFF (2011) *Proposed Australian Biofouling Management Requirements: Species of concern*. Canberra, ACT, Department of Agriculture, Fisheries and Forestry.
5. DAFF (2011) *Proposed Australian biofouling management requirements. Consultation regulation impact statement*. Canberra, Australia, Prepared for the Department of Agriculture, Fisheries and Forestry by PricewaterhouseCoopers.
6. Hayes, K. R. and Hewitt, C. L. (1998) *Ballast Water Risk Assessment - Vol II. CRIMP Technical Report Number 21*. Hobart, TAS, CSIRO Division of Marine Research.
7. Hewitt, C. L., et al. (2011) *Species biofouling risk assessment*. Canberra, Australia, Commissioned by the Department of Agriculture, Fisheries and Forestry
8. Hewitt, C. L., et al. (2011) *Vessel biofouling risk assessment*. Commissioned by Department of Agriculture, Forrestry and Fisheries.
9. MAFBNZ (2011) *Risk Analysis: Vessel Biofouling*. Wellington, New Zealand, Ministry of Agriculture and Forestry Biosecurity New Zealand.
10. Lee II, H., et al. (2010) *Density Matters: Review of Approaches to Setting Organism-Based Ballast Water Discharge Standards*. Newport, Oregon, U.S. EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Western Ecology Division. EPA/600/R-10/031.
11. Dafforn, K. A., Glasby, T. M. and Johnston, E. L. (2009) Links between estuarine condition and spatial distributions of marine invaders. *Diversity and Distributions* **15** (5) 807-821.
12. Piola, R. F. and Johnston, E. L. (2008) Pollution decreases native diversity and increases invader dominance. *Diversity & Distributions* **14** 329-342.
13. Edwards, P. K. and Leung, B. (2008) Re-evaluating eradication of nuisance species: invasion of the tunicate, Ciona intestinalis. *Frontiers in Ecology and the Environment* **7** (0)
14. Fitridge, I., et al. (2012) The impact and control of biofouling in marine aquaculture: a review. *Biofouling* **28** (7) 2012/08/01 649-669.
15. Fletcher, L., Forrest, B. M. and Bell, J. (2013) Impacts of the invasive ascidian *Didemnum vexillum* on green-lipped mussel *Perna canaliculus* aquaculture in New Zealand. *Aquatic Environment Interactions* **4** 17-30.
16. MPSC (2013) *National Prioties for introduced marine pest research and development 2013-2023*. Marine Pest Sectoral Committee.
17. Piola, R. F. and McDonald, J. I. (2012) Marine biosecurity: The importance of awareness, support and cooperation in managing a successful incursion response. *Marine Pollution Bulletin* **64** (9) 1766-1773.
18. DAFF (2013) *National Seaports Program: Australian Ballast Water Management Requirements (Version 5)*. Canberra, ACT, Department of Agriculture, Fisheries and Forestry.
19. FRDC (2010) *Working Together: the National Fishing and Aquaculture RD&E Strategy 2010*. Fisheries Research and Development Corporation.
20. McDonald, J. I. (2014) *Marine Biosecurity in Australia: A review of the national science capabilities*. Western Australia Department of Fisheries.