The growing role of underwater robotics as a first line of defence for protecting Australia's marine ecosystems

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Abstract
In a country where biosecurity is of ever increasing importance, and the impacts of invasive species are becoming ever more prevalent and far reaching, it is of paramount importance that the various stakeholders who use and rely on our oceans play their part in reducing the risk to their delicate ecosystems.

Approximately 14,000 international vessels enter Australian waters from overseas each year, many more transit between Australia's diverse marine ecosystems. The translocation of an Invasive Marine Species (IMS) via one of these vessels has the potential to cause irreparable environmental, economic, social/cultural and/or human health damage.

To date there have been over 250 IMS introduced to Australian waters. As a result, some native species have been displaced, adversely impacting the local fishing, aquaculture and tourism industries. For the past three decades, ballast water was considered the primary vector responsible for the dispersal of IMS around the world. However, recent research suggests the role of ballast water was probably overstated, and up to 69% of these introductions may have occurred via biofouling. To mitigate further introductions, and limit the spread of IMS, shipping requires management for both ballast water and biofouling.

Ballast water and hull inspections/verifications, while important, are costly and time consuming exercises. Mobilising divers to a vessel to conduct an inspection also brings with it inherent risks. Remotely Operated Vehicles (ROVs) allow for substantial risk reduction in subsea inspections, however costs have, in the past, been inhibitive.

Developing technology in the field of subsea robotics has now enabled greater access to ROVs than ever before. Ease of use and portability of systems now means that companies and individuals are now able to immediately conduct their own inspections without having to mobilise a dive boat, divers, etc. Not only does this ensure significant reductions in down time and risk to individuals but also allows more people much greater access to the environment.

This paper discusses the current systems in place around Australia to tackle the threat of IMS arriving via visiting vessels and compares the established use of divers for inspecting hulls with the growing availability of mini ROVs to provide an alternative solution.

While divers will always have an advantage over ROVs in terms of their ability to apply specialist knowledge/experience, collect samples etc, the cost, time and associated risks of deploying divers in dangerous waters often proves inhibitive.

This paper concludes and proposes a strategy of using mini ROVs to 'triage' arriving vessels to better determine which are more likely to harbour IMS and allow individual ports and companies to determine when and where to allocate diver resources to maximum effect.

Keywords: Biofouling, Invasive Marine Species, Marine Biosecurity, Remotely Operated Vehicles, ROVs, Surveillance.

1. Introduction

Australia is home to some of the world's most diverse and unique environments and species. Bordered by three oceans, three seas and with approx. 60,000km of coastline (incl. islands) [6], the marine environments of this island nation are one of its most prized and important assets. Indeed, Australia relies heavily on its oceans to provide income from (amongst other things) tourism, aquaculture and fishing activities and promotes itself to the world as being a pristine and beautiful environment.

As Table 1 shows, marine related industries represent significant value to Australia and its economy. For example, the Great Barrier Reef catchment area alone was responsible (in 2012) for approx. $7 billion direct expenditure and almost 70,000 jobs [4]. Many of these industries rely heavily on the marine environment remaining in good condition and relatively unimpeded by Invasive Marine Species (IMS) which are capable of causing catastrophic environmental, economic, social/cultural and human health impacts.

Table 1: Values of various Australian maritime industries

Industry	Value
Shipping	$ 9 billion (2012-13) [14]
Fishing & Aquaculture	$ 2.8 billion (2014-15) [7]
Marine tourism	$ 14 billion (2012) [13]

The fact that Australian coastlines have remained relatively pristine is due, in part, to their global isolation and the efforts of the nation's government and relative bodies to mitigate the arrival of unwanted IMS. As they have remained unchanged for so long an IMS, if allowed to establish, could disrupt the delicate balance of Australia's marine ecosystems to the extent that irreparable damage could be done, leading to large scale loss of habitats and decline in national income from various industries.

To combat this threat, numerous pieces of federal and state legislation including ballast water and vessel biofouling management, inspections and verifications requirements through to labelling and declaring specific species as a potential threat to Australia have been introduced.

It is vital to acknowledge that the costs of preventing an outbreak are far cheaper than combating one (Figure 1).

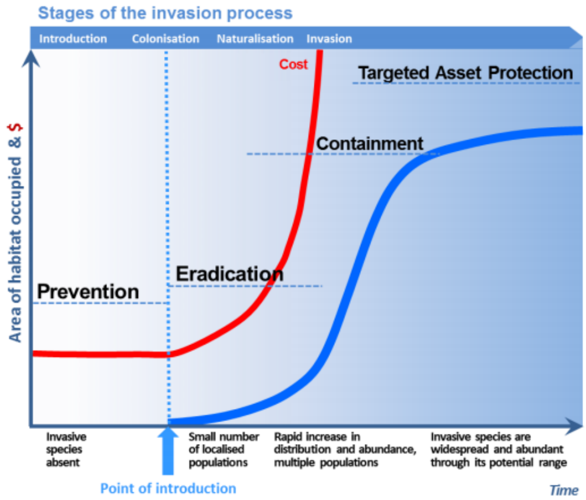

Figure 1 A graphic representation of the invasive process with Species proliferation (blue) and associated cost (red). (Source: [10])

2. Risk of introduction of new species

Approximately 14,000 international vessels enter Australia per year. Fortunately, the risk of IMS arriving via ballast water discharge is managed by Australia's Mandatory Ballast Water Management Requirements. However, to date there are no federal biofouling management requirements. One study estimated that one IMS has established in Port Phillip Bay, Victoria every 64 weeks since trade began [12]. In addition, the vast majority of IMS have established south of 30º latitude in Australia and not surprising these species originated north of 30º latitude in the northern hemisphere. Some examples of high profile IMS introductions in Australia are as follows.

2.1 *Asterias amurensis* – Northern Pacific Seastar

The Northern Pacific Seastar (NPS) was first confirmed in Tasmania in 1986, but is believed to have been introduced much earlier than that from ocean-going vessels originating from Japan [16], where comparable marine environments ensured that the NPS could thrive (see Figure 2).

Figure 2 Distribution of the Northern Pacific Seastar in Tasmanian waters as of 2009 (Source: [15])

Another colony was established in Port Philip Bay, Victoria in 1995, Believed to have been transported again via vessel across the Bass Straight from Tasmania [8], it is estimated that 2 years after being introduced to Victoria NPS numbers had reached around 12 million [8].

Since its establishment in Tasmania, the NPS has caused considerable damage to the states commercial shellfish fisheries including scallop, oyster, clam, and mussel aquaculture.

The NPS is an active predator and will feed on a wide variety of marine life whilst having a preference for shellfish. The largest impact has been on scallop production, valued at $25 million per year where, in 2006, 25 tonnes of NPS were caught as by-catch on the states east coast [1].

Female NPS spawn around 20 million eggs annually [16] and, given the right opportunities, could thrive in Australian waters ranging from Sydney in New South Wales (NSW) across the Southern coastline to Perth in Western Australia (WA) and represents a serious risk to soft sediment communities if allowed to spread [1].

2.2 *Mytilopsis sallei* - Black Striped Mussel

In 1999 outbreaks of Black Striped Mussels were discovered at a number of sites in Darwin, Northern Territory. Most likely to have been introduced from an international recreational yacht as hull biofouling or in seawater pipes, this mollusc originates from Central and South America and can tolerate a wide range of temperatures and salinities. Given its ability to thrive in a wide range of environments, this mussel has the potential to infest waters stretching from Fremantle in WA, across the north of the continent, and as far south as Sydney in NSW. Given the right conditions it could also establish colonies in Spencer Gulf and the Gulf of St Vincent in South Australia [2].

The 1998-99 Darwin outbreak reached densities of more than 20,000 per m^2 in its 5-6 month lifespan and cost more than $2.2 million to contain and successfully eradicate. It remains one of the world's only successful eradications of marine pests [9]. In contrast to the cost of eradication, this invasive species had the potential to cause widespread damage to Northern Australia's Pearling industry, worth approx. $67 million per year in Western Australia alone in 2014 [11].

While costly, it is worth comparing the effects and costs of colonisation of the black striped mussel to that of the closely related Zebra Mussel, *Dreissena polymorpha.* Introduced via ballast waters into North American ecosystems, mussel populations there have proliferated and now cost around US $750 million per year in removal and remedial engineering works [3].

3. Current management strategies

Current strategies for managing the unwanted arrival of IMS are spread between federal, state/territory governments and individual ports and Natural Resource Companies.

3.1 Government

At federal level, biosecurity matters are managed by the Department of Agriculture and Water Resources (DAWR). DAWR requires all vessels to register and submit information prior to arrival into Australian waters known as the Maritime Arrivals Reporting System (MARS). This determines their level of potential risk and also generates a Biosecurity Status Document (BSD). All information is submitted by the shipping agent/vessel master and must be submitted no less than 12 hours prior to arrival. While the DAWR presently manage the introduction of IMS via their mandatory ballast water management requirements, presently there are no vessel biofouling management requirements.

While most State/Territory Governments possess either existing or amended legislation capable of managing the unwanted introduction of IMS, the

Western Australian Department of Fisheries (WA DoF), is leading the way.

In particular, the WA DoF has developed an online decision support tool called 'Vessel Check'. Similar to the federal MARS system, it is a voluntary reporting system to help visiting vessels determine their theoretical likelihood of introducing unwanted "noxious fish" into WA state waters.

There are risks associated with having numerous organisations working individually to tackle the threats associated with IMS. Varied and even disparate strategies which might not complement each other can lead to an uncoordinated approach to a serious national issue.

However, it is important to note that the scale of Australia, combined with its diverse range of marine environments and conditions means that it is difficult for one governmental policy or management strategy to be suitable for all of the countries ports and harbours. Different regions/ports experience vastly different levels and types of marine traffic and are under threat from different types of IMS.

While a coordinated national approach is very important in directing efforts to combat the unwanted arrival of IMS, a localised 'tailored' strategy (e.g. unique to the particular environment or port activity) may also be justified.

3.2 Ports and Natural Resources Companies

Ports around Australia are obligated to manage against any threats to the marine environment, which could be argued to include IMS. For example, the *Darwin Port Corporation Act* (*DPCA*) enables the Port to be managed by the Darwin Port Corporation (DPC) which under the Northern Territory's Department of Primary Industries and Fisheries (DPIF) operates a compulsory hull inspection protocol for vessels wishing to enter Darwin's lock-accessed marinas. The current protocol requires any foreign fishing vessel or yacht arriving from an overseas port (or the Port of Cairns) to have its hull inspected by diver or haul-out inspection and its internal seawater systems treated. Exceptions include vessels which have been recently antifouled within Australia and have subsequently not entered international waters, or vessels which have been out of the water for at least two months. Vessels intending to remain in the open harbour of Darwin and not enter any of the marinas do not have to undergo inspections or treatment.

Some oil & gas exploration companies have also developed and implemented their own IMS management strategies. For example, Woodside Energy Limited has developed their own Invasive Marine Species Management Plan which requires all vessels associated with their operations in Australia to be risk assessed and if need be inspected and cleaned prior to being contracted. Chevron Australia Pty Ltd has also developed some of the highest marine biosecurity management requirements associated with their famous Gorgon LNG Project on Barrow Island and their Wheatstone Project at Onslow, Western Australia.

3.3 Third parties & contractors

Many third party companies now offer (either exclusively or as part of their suite of services) hull inspection and cleaning services. These companies range from larger scale survey, commercial diving and ROV companies to small operation sole-operator divers. The vast number of vessels visiting Australia from overseas and the popularity of maritime activities around the country has created good conditions for an industry to develop and thrive. Both diver and ROV services can be employed, with options ranging from single dive inspection services to the use of ROVs and 'turn-key' automated systems which can both survey and clean vessel hulls.

Due to the number of vessels moving into and around Australian waters throughout the year it is impossible to inspect them all, especially in the larger, busier ports. Hence, the vast majority of vessels inspected for IMS in Australian waters are those which have been risk assessed as posing a high or uncertain theoretical risk of introducing IMS into Australian waters and require verification by either WA DoF or the various Resource Companies.

Biofouling Solutions Pty Ltd. has conducted over 300 vessel inspections over the past eight years and detected IMS on 25% of these vessels (i.e. one in four vessels). Hence, one can only imagine the number of vessels which may be entering Australian waters with IMS which are going undetected/unmanaged. To inspect more vessels using commercial divers is cost-prohibitive. However, the use of ROVs may well be a feasible alternative as the first defence against protecting Australia's marine environment from the unwanted arrival of IMS on vessel hulls.

4. Methods of inspection for biofouling

Until relatively recently, most vessel inspections were conducted with the use of commercial divers. As such, diving has an established role in the subsea inspection and maintenance of vessel hulls, aquaculture netting, and port infrastructure.

Remotely Operated Vehicle (ROV) technology meanwhile, while not new, has always been accompanied with inhibitive costs and other barriers to entry, meaning that diving was the best method for inspection and maintenance of vessels and subsea infrastructure. Maturation and development of technologies have led to cost reductions and miniaturisation of ROVs, enabling more entrants to market and broader scopes of application.

Studies [5] conducted into the use of ROVs for biofouling inspections and comparing them to the use of divers have found that both mediums have significant advantages and disadvantages in this field.

4.1 Efficiency of inspection

Once deployed, inspections of vessel hulls are found to be highly efficient when using divers. Divers have a good range of movements and spatial awareness which allows them to inspect the more complex areas on a vessel (e.g. chains, intakes, rudders and anodes) without (sea state depending) too much difficulty. 100% of the target locations in the study were able to be assessed by the diver.

Free flying ROVs experienced some difficulty to manoeuvre around certain objects due to the proximity to the hull and other structures. Maintaining a stationary position was also more challenging with a free flying ROV than a diver due to vessel motion and wave/current action. This issue was found to be more prevalent when inspecting vessels in offshore locations as opposed to wharfside. ROVs were found to be able to access only slightly less target locations than divers [5].

It was also noted that when using a diver, the 2 way radio link, wide field of vision and ability to interact with and interpret what they are seeing in front of them made conducting in depth hull surveys more efficient and effective than with solely using an ROV. Experienced divers might also be able to alert inspectors on the surface to the presence of biofouling outside the range of their helmet camera [5].

4.2 Recorded data and sample quality

In both wharfside and offshore conditions, ROVs were found to be able to collect higher quality video footage than divers. Even when stationary, divers tended to move more, leading to increased camera motion and a less clear image for detailed interpretation of biofouling organisms. This was found to be more prevalent in offshore conditions, where divers were greatly affected by wind induced wave and swell [5].

Conversely, still camera images were of better quality when collected by divers rather than when taken from ROV video footage. ~75% of images acquired by divers were able to be used to distinguish biofouling taxon and even genus or species. ROV stills, however, could only enable detection of the presence of biofouling but no identification could be made [5]. It is worth noting that this study did not take into account images taken from ROV with dedicated high definition still cameras.

Physical samples of various attachment strengths to the hull were recovered in good condition with relative ease by divers in each of the test cases. All samples required a single attempt at recovery and took approx. 1 minute per sample. All samples were returned to the surface in a condition suitable for identification. The ROV on the other hand experienced more difficulty during sample collection, even during calm wharfside conditions. Firmly attached organisms were unable to be removed and each successful sample required 2-3 attempts and 1-5 minutes for recovery. It is clear that divers possess a dexterity and advantage of being able to analyse the task in-situ and coordinate their actions to enable successful sample collections. ROVs on the other hand found this more challenging, even when operated by a skilled pilot [5].

4.3 Other factors

Set up times and preparation for inspection were considerably longer and more complicated for dive teams than for ROVs. Prior to each inspection the dive team took 45 minutes to dress and prepare both a diver and stand-by diver, initiate a compressor, connect and test video, lighting and communication equipment and conduct all safety checks and team briefings [5].

In comparison the ROV used in the assessment took 25 minutes to set up the vehicle, topside control panel, 240v power source and test all systems. Other commercial grade ROVs are now available in the marketplace which do not require external power sources, do not have large topside control units and can be set up and ready to dive within approx. 1 minute of arriving on site (see Figure 3).

Figure 3 Small commercial ROV (Source: Deep Trekker)

Overall, the costs associated with contracting a locally sourced commercial dive team to conduct a wharfside inspection are generally 6 times greater than hiring a locally based small ROV [5]. This is due mainly to the large amounts of equipment and personnel required to mount a dive survey, whether wharfside or offshore. A large part of the cost is the requirement for a dive support vessel which is not required by an ROV team which can mobilise on the wharf or vessel itself.

Costs incurred for hull inspections would be further reduced if the port/harbour/vessel company requiring an inspection to be carried out were able to retain the ability to conduct such an investigation 'in-house'. While this is more difficult to achieve with a dive survey, the affordability, ease of use and diminishing barriers to entry surrounding small ROVs are making in-house hull inspections a realistic and achievable option.

Health and safety is of paramount importance to all employers, especially in the maritime sector. There are always inherent risks in most activities and hull inspections are no exception. Tides, waves, wind, moving parts (propellers, rudders, anchor chains, etc.) and even marine predators pose varying levels of risk. Before a biofouling inspection is to be undertaken a risk assessment is usually conducted, especially in the case of dive surveys, and if the inherent risks is found to be too great then this can lead to delays. ROV inspections, while still affected by tide/wave action, etc. do not face as many risks as divers simply due to the fact that a human being does not need to enter the water.

5. Discussion

As a result of the study, it was found that there were strengths and weaknesses associated with both methods of inspecting vessel hulls for biofouling (summarised in Table 3 below).

Table 3: Strengths/ weaknesses of diver & ROV surveys

Parameter	Diver	ROV
Efficiency	✓	
Video footage		✓
Still images	✓	
Sample collection	✓	
Inherent risk		✓
Cost		✓
Mob / Response time		✓

Divers, particularly those with a detailed knowledge of biofouling and IMS, present the most efficient way to conduct a thorough and comprehensive inspection of a vessel arriving in Australian waters. Species can be identified while the diver is still in the water and samples can easily be collected. Divers can also record still images to a degree of quality that details of a species can be identified.

However, it is clear that the cost and logistical challenges of mobilising a dive team to site (extra vessels, equipment, long mobilisation times, etc.) are prohibitive to the client. The health, safety and weather issues that have to be taken into consideration when planning a dive survey can also cause extra problems or time delays. In a busy port, delays to large vessels or vessel schedules due to waiting on a hull survey can prove extremely costly.

The simpler and smaller amounts of equipment involved ensure that an ROV spread can be up and running much faster than a dive team can. Without the need for anyone to get into the water large amounts of health, safety and weather considerations are no longer an issue. Video footage recorded is of excellent quality and ROVs do not seem to be affected from as much motion issues in open water environments as divers are, especially ROVs which have the ability to attach or maintain contact with the hull/surface. However, the sampling capacity, quality of still images and the efficiency at which an ROV can conduct a hull inspection (particularly in intricate or difficult areas) means that divers will usually be able to deliver a consistently high quality result. That being said, the mobilisation time, cost-efficiency and health and safety advantages of ROVs ensure that this option is still highly advantageous for the port/harbour/vessel operators, etc.

6. Conclusion

The potential threats posed to Australian waters, ecology and industries by IMS has been proven, with numerous incidents occurring at home and internationally. With an increasing number of marine traffic visiting Australian waters each year and the absence of any nationally coordinated biofouling management measures there is an increased risk of more IMS establishing.

Australia's federal and state/territory governments and agencies acknowledge the severity of the issue and are doing their best to protect the country against the unwanted arrival of further IMS. However, with such a large and diverse country, and so many vessels entering Australia's ports and harbours, it is not realistic in the current format to implement a comprehensive inspection/verification regime.

With the advent and advancement of subsea robotics in the form of small ROVs it is now possible for ports, harbours and even vessel operators to possess their own ROV units and immediately conduct their own investigations without the need to engage expensive third party contractors. Such capability can also assist other government departments such as the Australian Department of Immigration and Border Protection against the unwanted arrival of illegal drugs and substances which can also be attached to vessel hulls.

The advantages of retaining an inspection capability in-house enables a port or harbour to, in effect, 'triage' arriving vessels and then decide which require a more detailed inspection with a dive team. Small ROVs are now so portable that they can be transported and operated by one operator from a small vessel or wharfside vehicle.

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