Received: 21 June 2019 | Accepted: 5 November 2019
DOI: 10.1111/1365-2664.13557

PRACTITIONER'S PERSPECTIVE

Journal of Applied Ecology | BRITISH ECOLOGICAL SOCIETY

A united front against marine invaders: Developing a cost-effective marine biosecurity surveillance partnership between government and industry

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Handling Editor: Verena Trenkel

Abstract

1. Successful detection of introduced marine pests (IMP) relies upon effective surveillance. However, the expedience of responding following IMP detection is often dependent upon the relationship between regulators and stakeholders.
2. Effective detection of IMP in areas such as commercial ports requires a collaborative approach, as port environments can be highly complex both above and below the water. This complexity can encompass physical, logistical, safety and legislative issues. With this in mind, the aquatic pest biosecurity section within the Department of Primary Industries and Regional Development (DPIRD) developed the State-Wide Array Surveillance Program (SWASP) in collaboration with Western Australian Port Authorities and port industry stakeholders.
3. The SWASP is primarily based on passive settlement arrays for IMP detection. Arrays are deployed at strategic locations within Ports. Marine growth samples collected from the arrays are processed using Next-Generation Sequencing (NGS) to identify the presence of IMP within a specific geographical location.
4. Over 8 years, participation in SWASP has grown from 3 to 11 ports, spanning over 11,000 km, from the tropical north to temperate south of Western Australia. The programme has proven to be highly effective as a means of fostering stakeholder involvement and, importantly for IMP surveillance. The growth and success of SWASP has continued primarily because of the commitment and farsightedness of the ports involved. The regular presence of the biosecurity regulator as a partner in SWASP has provided a consistent face for biosecurity and fostered good stakeholder relationships, ensuring there is a reliable and effective ongoing marine surveillance programme for the state.
5. *Synthesis and applications.* Through a united and collaborative approach to marine biosecurity surveillance, port authorities, industry and biosecurity regulators have developed the State-Wide Array Surveillance Program (SWASP) and closed a

major gap in biosecurity surveillance. The SWASP collaboration uses passive settlement arrays and molecular analyses to provide regular marine pest surveillance from the tropics to temperate regions of Western Australia. The continued commitment has embedded valuable relationships between stakeholder and regulator ensuring ongoing surveillance in marine biosecurity for the state. The Western Australian SWASP example has inspired other jurisdictions around Australia to develop similar collaborative approaches which will have far-reaching marine biosecurity benefits.

KEYWORDS

biosecurity, collaboration, marine pest, partnership, port, programme, stakeholder, surveillance

1 | INTRODUCTION

The global spread of marine species is recognized as a threat to coastal ecosystems and their associated values (e.g. Bax, Williamson, Aguero, Gonzalez, & Geeves, 2003; Costello et al., 2010; Molnar, Gamboa, Revenga, & Spalding, 2008). While species can spread by many means, some marine areas, such as ports, are more susceptible than others to the establishment of introduced marine pests (IMP; Floerl, Inglis, Dey, & Smith, 2009). This is a consequence of the rise in international vessel movement in recent decades via the proliferation of trade and tourism, resulting in an exponential increase in marine species being translocated to areas outside of their natural ranges (Carlton, Keith, & Ruiz 2019; Floerl et al., 2009; Hulme, 2009; Leung et al., 2002; Levine & D'Antonino, 2003). Introduced marine pest are 75% more likely to become established in busy ports than quieter locations, and in turn, these ports can increase the likelihood of spread of IMP to other areas (Floerl et al., 2009). Ports per se are not creating the risk; rather, they are the nodes through which vessels arriving from international destinations can potentially relocate IMP through ballast water or hull biofouling. While there are some regulatory controls to reduce the likelihood of IMP translocation into Australian waters (DAWR, 2017; WA Govt, 1994; 2016), ports operating as transport hubs (nodes) have a vested interest in limiting the potential establishment of any IMP and will benefit from implementing IMP surveillance and management programmes. Ports interests primarily lie in their environmental licence to operate which under the Environmental Protection Act (1986) requires protection of the environment managed by the port. The protection of the trade (economic value) that flows through ports in Australia/WA is also a key driver as a pest outbreak could impact trade in/out of the affected port.

Introduced marine pests surveillance can be logistically challenging and economically expensive to undertake. The ability to conduct IMP surveillance is constrained by the very nature of the marine environment, which is generally large and complex, with high biological diversity that is often not fully appreciated or understood (Giangrande, 2003; St. Pierre & Kovalenko, 2014). Commercial ports typically have highly complex environments both above and below the water. As these conditions are often compounded by logistic, legislative, operational and safety issues, the implementation of surveillance programmes can be particularly challenging. These constraints can limit what can be achieved, requiring marine surveillance to be specific to the port environment and fit for purpose to ensure that IMP can be detected and managed effectively.

Early detection is the most cost-effective way of minimizing the risk of IMP establishing and their subsequent management (Coutts & Forrest, 2007; Kaiser & Burnett, 2010; Marchetti, Moyle, & Levine, 2004; Simberloff et al., 2013). Once established in a new habitat, IMP are notoriously difficult to eradicate (Coutts & Forrest, 2007; Hewitt & Campbell, 2007; Meyerson & Reaser, 2002; Thresher & Kuris, 2004).

Successful management of IMP incursions relies upon several key factors. These include the following:

- identification of vectors and risk pathways and alignment with measures to reduce IMP introduction likelihood,
- awareness (by all) of the potential risk of incursions, and appropriate protocols and surveillance for early detection and identification of IMP showing pest-like characteristics,
- rapid response following the detection of potential IMP, and importantly,
- support and cooperation between stakeholders (e.g. industry, public) and regulatory agencies in the response process (Piola & McDonald, 2012).

Early IMP detection is most likely to occur and be effective if cohesive surveillance and management programmes are in place (Bax et al., 2001; Mehta, Haight, Homans, Polasky, & Venette, 2007), with IMP surveillance programmes linking regulatory agencies to port operators and industry stakeholders generally thought to be the most effective (e.g. Piola & McDonald, 2012). An effective response to an IMP incursion can hinge upon this collaborative arrangement, as early detection and reporting may prove ineffective if a rapid and coordinated response is not subsequently applied (McAllister et al., 2017). Yet to the best of our knowledge, such joint or cooperative surveillance programmes are rare both within Australia and world-wide.

This manuscript highlights the importance of cooperation and collaboration between regulatory agencies, Port Authorities and industry stakeholders to manage IMP surveillance in commercial ports. We showcase the growth and development of an IMP surveillance programme from one site at a single port to a state-wide stakeholder-driven IMP surveillance programme, including the lessons learned from the evolution of this approach.

2 | NATION-WIDE SURVEILLANCE PROGRAMMES: SUCCESSES AND LIMITATIONS

Australia and New Zealand, being ocean-bound nations, are particularly dependent upon shipping for transportation of goods (Piola & McDonald, 2012). These countries have wide-ranging approaches to marine biosecurity (DAWR, 2017; 2019; DoE, 2015; Hewitt & Campbell, 2007; MPI, 2018), primarily in response to the high risk of introduction and establishment of IMP faced through the ever-increasing vessel movements (see CLIA, 2017; Floerl et al., 2009; Seebens, Gastner, & Blasius 2013). In 2002, the New Zealand government commenced a national surveillance programme at 11 high-risk ports and marinas around New Zealand (Ministry for Primary Industries, 2017). Similarly in 2010, the Australian government implemented the National System for the Prevention and Management of Marine Pest Incursions (hereafter National System) aimed at decreasing the risk of IMP establishing in Australia and reducing the impact and spread of IMP already present (DAFF, 2010). The National System aimed to detect and manage IMP in 18 high-risk ports throughout the country. The locations were determined primarily on the number of vessel movements, with an assumption that the greater number of vessels the greater the likelihood of IMP incursion. The National System used a process of listed target species, known surveillance detection method probabilities, and defined sample effort to achieve an overall programme confidence. Following a species-based approach, the system focused effort on extensive sampling of all potential habitat types for each target species rather than a more fit-for-purpose sampling regime appropriate to the risk vectors and port environment. The System was seen as a breakthrough in Australia and internationally, in terms of being a programme that was agreed to nation-wide, with a robust design and a consistent approach to marine biosecurity surveillance.

Both the Australian and New Zealand marine biosecurity surveillance programmes were managed and operated by government regulatory agencies. The New Zealand monitoring programme has been highly successful and is an ongoing central-government-funded programme (Ministry for Primary Industries, 2017). The Australian National System, although based on the same principles, has met with difficulties, particularly in relation to implementation and maintenance of the programme across the States and Territories. Perhaps one of the key differences between the approaches of the two countries was that the NZ surveillance was centrally funded. Due to a lack of centralized funding or strategic coordination, there were inherent difficulties associated with applying the Australian system across state boundaries that the New Zealand system did not encounter.

In practice, there were considerable shortcomings associated with implementing the Australian National System. Like the New Zealand surveillance programme, the National System relied upon large skilled teams, to implement the programme and was onerous in terms of the amount of field surveillance effort required. New Zealand has somewhat overcome this hurdle by outsourcing the surveillance to a provider with dedicated, well-trained consistent teams. Most states in Australia lacked dedicated and capable staff to implement the field and laboratory-based aspects of the programme. High operational costs, often requiring in excess of AUD$350,000 per port surveillance event, and slow post-survey processing of samples for identification made the National System unwieldy. Furthermore, as the programme was only to be implemented every 2 years, it was likely that an IMP could become established in the port between surveillance events.

Despite the nation-wide agreement, the National System was implemented in only five out of the 18 specified locations, with the majority of states never implementing the System at all. These limitations amounted to critical shortcomings in terms of the National System being an effective nation-wide programme.

In Western Australia, the National System ran for 5 years (2011–2015) through state government funding and targeted each of the locations assessed as having a high risk of potential IMP incursion; the ports of Dampier, Fremantle and Port Hedland. In addition to the high costs of implementation, access to many areas within ports such as Dampier and Port Hedland were restricted due to safety exclusion zones around port terminal operations and the risk associated with hazardous marine fauna (e.g. crocodiles). This limited in-water activities in certain areas and all surveillance staff were required to meet strict occupational health and safety, diving, and oil and gas project-specific standards (in Dampier), well above those generally required within regulatory agencies. Due to these limitations, continuing the National System in Western Australia was not considered viable. Given the importance of IMP surveillance, refining the scope and resource requirements of the programme was deemed necessary, and resulted in substantial retractions of surveillance activities in the aforementioned port environments.

Recognizing the limitations associated with implementing the National System, the Aquatic Biosecurity section within the Department of Primary Industries and Regional Development (DPIRD), Western Australia (hereafter known as the Department) explored alternatives to ensure a consistent and more cost-effective IMP surveillance programme. The Department developed a new approach to IMP surveillance, in which collaboration and cooperation with port and industry stakeholders were actively sought. This resulted in port stakeholders and the Department working in tandem to share ideas, costs and knowledge to develop and implement an IMP surveillance programme.

3 | DEVELOPMENT OF A COLLABORATIVE SURVEILLANCE PROGRAMME

To engage the port stakeholders in a more cost-effective IMP surveillance programme, the early warning system (EWS) was implemented in Western Australia in 2010. At the time of implementation, the EWS was developed to provide passive year-round in-water surveillance to complement the larger National System. The array programme also complimented the smaller targeted surveillance programmes conducted during interim years in the three WA National System ports.

Under the EWS surveillance programme, a range of IMP detection tools were used. This included settlement arrays, crab traps, crab condos and shoreline surveillance. Each of these methods have been shown to be effective tools in IMP surveillance (Hewitt & McDonald, 2013; Marraffini, Ashton, Brown, Chang, & Ruiz, 2017; Tait & Inglis, 2016). For example, settlement arrays consist of a set of small plastic plates that provide vacant space upon which marine organisms can settle and grow (Figure 1). Arrays rely on the way in which organisms naturally encounter a settlement surface as they are dispersed through the surrounding environment, there is no specific attractant for the organism aside from the vacant settlement surface or other organisms that settle on that surface.

The cooperative development of the EWS between the initial participants led to a high level of trust and engagement associated with the implementation of the programme. This resulted in the expansion of the EWS to more ports along the Western Australian coastline. Currently, there are 11 State and private ports voluntarily involved in this collaborative approach to IMP surveillance interspersed along approximately 11,000 km of the Western Australian coastline (Figure 2).

3.1 | Developing a collaborative surveillance programme—version 1.0

The initial version of the EWS, deployed settlement arrays (Figure 1) within each port four times a year. In consultation with port staff, arrays were situated in areas where the interaction with high-risk vectors (e.g. international and relocating domestic vessels) was greatest while eliminating potential impacts on vessel operations or safety. To favour potential entrainment of larvae, array placement considerations also included port hydrodynamics as well as protection from environmental and physical disturbance (wave action, swell, ship wake and frictional wear). After a 3-month immersion period, arrays were removed from the water and analysed visually by trained Department

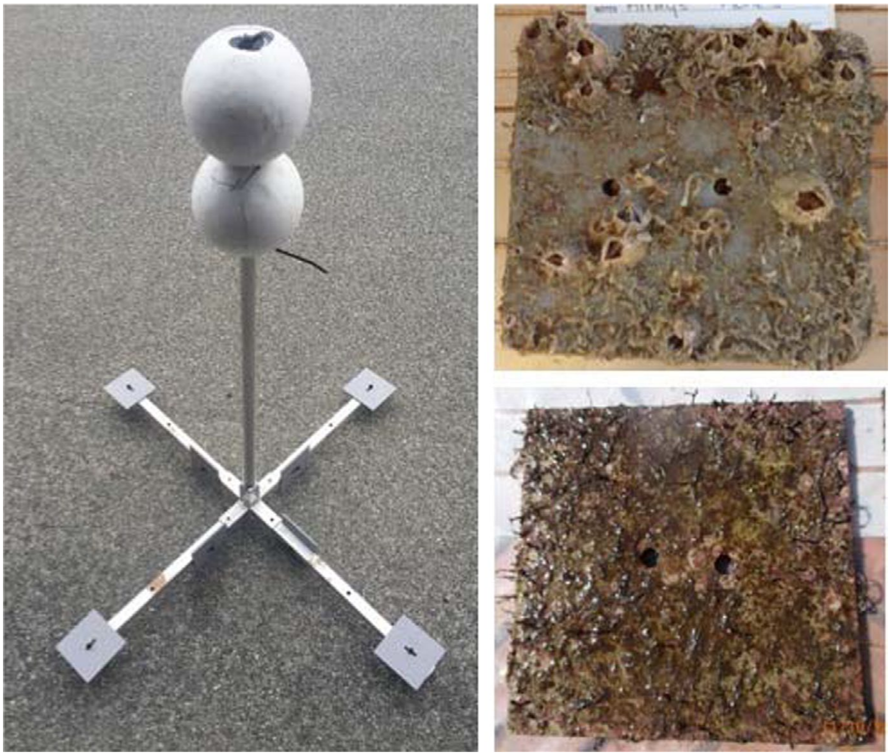

FIGURE 1 Image of the settlement array structure showing the floatation and metal arms complete with square plastic plates (left hand side). The structure sits approximately 1m below the water's surface. The arms each contain both horizontal and vertical plates constructed of PVC. These plates provide a clean 'competition free' substrate for any marine larvae to settle on. These arrays are deployed in ports along the Western Australian coastline and provide an early warning system for the detection of any founding populations of introduced marine pests as well as a record of other marine organisms in the surveys area. The arrays are immersed in water for a period of two months (right hand side) after which they are retrieved by Port staff, photographed and the images and plates sent to marine pest experts for examination and analysis using molecular tools to detect if a marine pest is present.

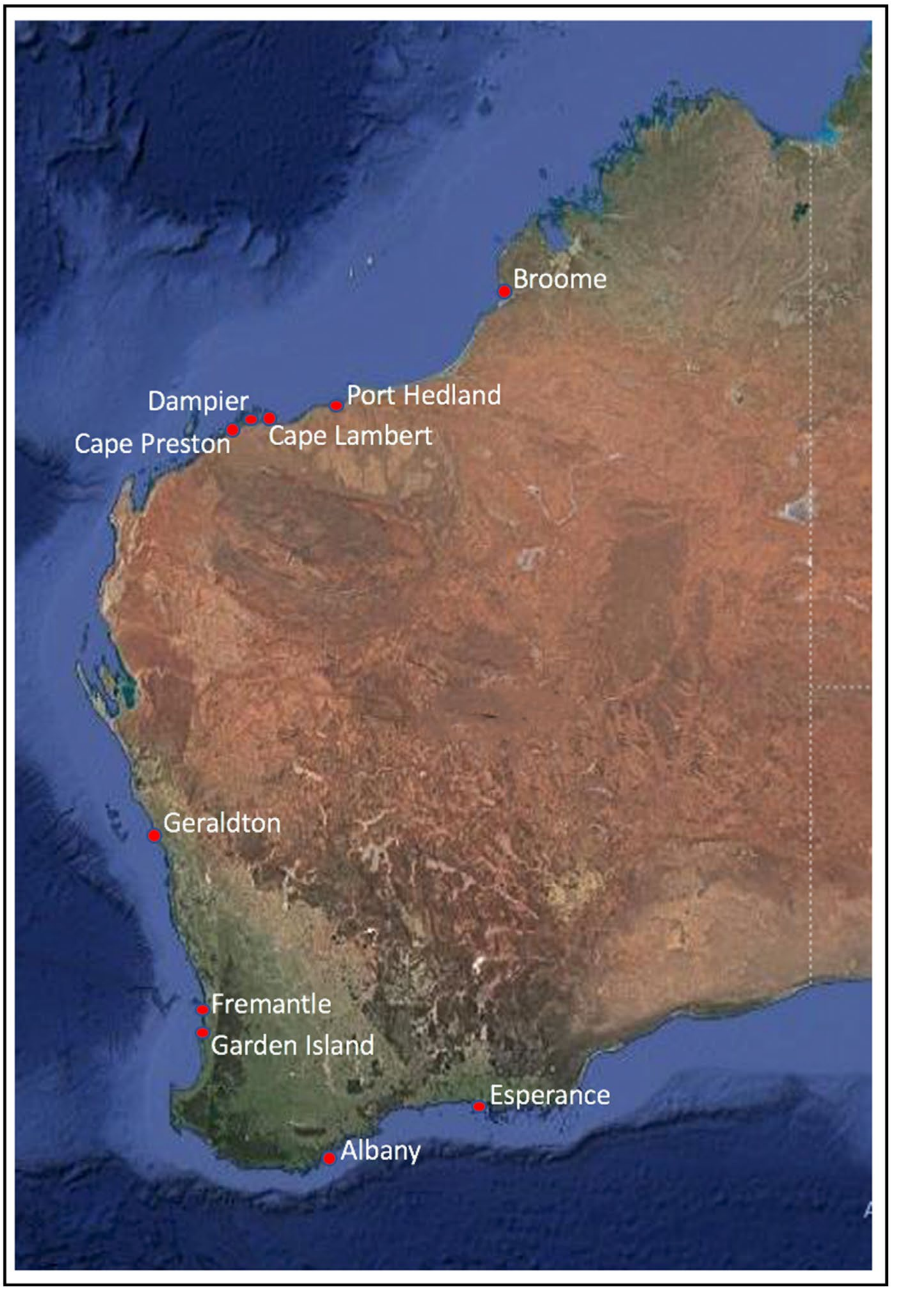

FIGURE 2 Location of ports involved in State-wide Array Surveillance Program. Base map courtesy of Google Maps

staff for the presence/absence of IMP, or taxa displaying pest-like characteristics. Integral to the collegial nature of the programme was that port staff were directly involved in the deployment and retrieval of sampling equipment and collection of samples. Crab traps and condos were deployed by Departmental staff at the same sites 24 hr prior to array removal. After 24-hr immersion Department and port staff would remove arrays, traps, condos and also undertake shoreline surveillance, searching through wrack and debris on the shore for algae, shells, crabs and crab carapaces for any evidence of IMP. This provided the opportunity to enhance engagement with the port's staff by providing them with ongoing training in IMP identification and awareness. This version of the EWS programme was limited to those organisms that could be readily identified through morphological examination and taxonomic identification.

3.2 | Enhancing a collaborative surveillance programme—version 2.0

In 2015, the Department undertook a review of its marine biosecurity surveillance programmes. Within the EWS programme, the review highlighted the potential to move from a traditional taxonomic identification approach to one based on utilizing new molecular-based tools. The reliance on visual identification of samples was biased towards high-to-medium abundance organisms that were easily identifiable and meant that many organisms had to reach a certain size before they could be identified. Similar to the National System, seeking specialist advice to verify a species identification was often limited due to associated cost, time constraints and diminishing taxonomic expertise (Visher, 1996). Thus, the development of molecular-based tools was identified as a mechanism that could assist with the early detection and identification of IMP. In particular, this technology could theoretically detect and identify larvae, juveniles, fragments (pieces or shed cells) from organisms that may not be possible using traditional approaches.

The EWS was transitioned into the State-Wide Array Surveillance Program (SWASP) in mid-2016. The rebranding was appropriate based on the incorporation of the new molecular-based approach (Next-Generation Sequencing NGS) and the far-reaching and inclusive nature of the programme. During the transitional phase (mid 2016–mid 2017), the sampling periodicity was changed from four to two deployments (summer and winter only), allowing for greater temporal flexibility while the new methodologies, analytics and reporting processes underwent development. Methods were refined to focus on the settlement arrays and shoreline surveillance within each Port. In addition to the detection of target IMP, NGS has provided a more detailed window into the marine biodiversity that exists in each port environment which through the SWASP molecular profiling has been shown to have high species diversity and complexity.

The programme has been highly successful to date for both the regulator and stakeholders, with growth in mutual trust, communication and confidence. The success of the programme is exemplified by recommendation of the SWASP by port collaborators to their counterparts and regulators in other parts of Australia, as a suitable, cost-effective programme for marine biosecurity surveillance.

Although there are some limitations of the SWASP in terms of spatial sampling, the programme has many positive attributes that set it apart from the National System.

- The direct contribution of the WA Port Authorities and industry partners to the development of the SWASP system has engendered a sense of stakeholder ownership towards the programme, which brings with it a willingness to continue surveillance, support research developments and to share information beyond any direct regulatory requirement.
- The SWASP is cost-effective (approximately 10% p.a. of National System costings).
- Surveillance occurs in ports every 6 months under SWASP. This change in frequency alone greatly increases the likelihood of detecting an IMP.
- Finally, and most importantly, the SWASP is an ongoing programme that has had major uptake through the collaborative approach between regulators and stakeholders.

4 | THE PATH FORWARD: LESSONS LEARNED FOR ENHANCING BIOSECURITY SURVEILLANCE THROUGH COOPERATION BETWEEN REGULATORY AGENCIES AND INDUSTRY STAKEHOLDERS

The SWASP has proven to be a very effective tool for IMP surveillance and, importantly, a means of valuing and engaging stakeholders. To date, the authors are not aware of any other truly collaborative approach where stakeholders, such as State ports and private operators, have actively funded, helped develop, refined and implemented IMP surveillance without any external pressure, which is typically driven through regulatory controls and licencing. Regular presence and consistent messaging of Department staff through the SWASP have provided a face for biosecurity and fostered and maintained ongoing stakeholder relationships. In some instances, State ports have engagement with individual port operators (tenants), sharing the information and costs associated with the individual port surveillance programmes. The continued engagement by the Department reinforces a biosecurity presence, and supports the need for biosecurity surveillance and reporting outside of formal regulatory mechanisms.

As the programme is predominantly stakeholder funded, the Department has been working to maintain its cost-effectiveness while optimizing particular aspects. In their recent review of settlement arrays as a surveillance tool, Tait and Inglis (2016) highlight that species with short larval life spans (hours) or aggregated with settlement patterns may require sampling surfaces located close to spawning point, or conversely, surfaces that are more widely dispersed to encounter any ‘swarm’ of propagules. The Department is currently optimizing array site selection through three-dimensional environmental modelling to predict potential dispersal for different larval types under varying conditions. The likelihood of a propagule encountering an array is determined by the concentration of larvae in the water and the movement of that water over time. Modelling of different larval types (e.g. passive and neutrally buoyant, active swimmers with phototaxic responses) from vessel berthing areas will also be conducted over a range of temporal scales. The accumulation and analysis of these dispersal patterns will help identify likely hotspots for optimum array deployment. Once site optimization has occurred, we will work with our port and industry stakeholders to review deployment locations, retrieval times and the number of replicates at each site to increase programme confidence.

The Department is also refining the molecular-based tools within the SWASP to provide greater confidence in detection and identification and to reduce processing costs and times. Currently, techniques are restricted to parts of the genome such as 18s, 16s or CO1. By targeting a greater number of unique regions across more of a species genome for each target species, we can potentially increase diagnostic specificity and confidence. The ultimate aim of the abovementioned work is that each port will have a tailored surveillance programme designed to offer greater confidence in IMP detection that is better value for money.

The success of the SWASP is based on the formation of a shared collaborative approach to marine pest surveillance between port stakeholders and the Department. This success has been recognized in the field of biosecurity at both State (Western Australia Golden Gecko Award for Environmental Excellence 2018) and national levels (Australian Biosecurity Award for a significant contribution to maintaining Australia's biosecurity integrity 2019). Through the development process, many valuable lessons have been learned that should be taken into consideration by regulators and stakeholders who are contemplating undertaking similar biosecurity surveillance programmes. These focal lessons include the following:

1. Work with bodies that are willing to work with you. Do not spend initial efforts in ongoing dialogue with those who do not wish to participate. Our experience has shown the value of the initial participants, even though they may not be located within highest risk areas. These ground-breaking participants can influence others to join via the groundswell of acceptance and participating peer pressure.
2. Do not aim for perfection in the initial surveillance programme, rather the understanding should be that 'something is better than nothing'. It is important to develop a collaborative approach to surveillance that parties can agree upon. The sampling regime and fine-tuning of the surveillance protocol can be built upon and evolve as time progresses.
3. Understand that a single system will not fit every environment: threats, habitats and stakeholders vary. Consequently, an effective surveillance system has to be adaptable to risk and size.
4. Be open to learning from your stakeholders. Stakeholders have a wealth of knowledge and consequently are better situated to advise on their environment and specific considerations for implementation. Regulators need to listen and learn from stakeholders, and in this way, a constructive and effective surveillance pathway can be created.
5. Finally, and most importantly, work together. Do not try and impose a rigid regulatory approach where one party dictates to the other. A truly collaborative programme will achieve greater participation and as a consequence, far greater success. Biosecurity should always be a shared responsibility, and a united front is the only way forward in the fight against marine invaders.

ACKNOWLEDGEMENTS

The Department would like to acknowledge our port collaborators, without their trust and support this programme would not be possible. We would also like to acknowledge the support of previous staff members involved in this programme: Mathew Hourston, Julieta Munoz and Tiffany Simpson. Ports would like to acknowledge past and current staff and management from the various WA ports who have supported this initiative beyond the normal compliance frameworks. Ports also acknowledge the input and support provided by our tenants, some of whom have been strong supporters from the outset. Environmental stewardship of our ports is a shared belief and the SWASP clearly demonstrates our willingness to monitor, understand and better manage our environmental assets. We are very grateful to the two anonymous reviewers whose comments and feedback significantly improved this manuscript.

AUTHORS' CONTRIBUTIONS

J.I.M. conceived the initial ideas and designed the SWASP. All authors contributed to the ongoing implementation, refinement and management of the SWASP. J.I.M. led the writing of the manuscript with G.C. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data have not been archived because this article does not use data.

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How to cite this article: McDonald JI, Wellington CM, Coupland GT, et al. A united front against marine invaders: Developing a cost-effective marine biosecurity surveillance partnership between government and industry. *J Appl Ecol*. 2020;57:77–84. https://doi.org/10.1111/1365-2664.13557