Environmental Risk Mitigation Plan
for Mangroves and Associated Communities

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Plant Health AUSTRALIA

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List of acronyms

AUV	Autonomous Underwater Vehicle
BICON	Australian Biosecurity Import Conditions Database
CAFNEC	Cairns Far North and Environment Centre
CCIMPE	Consultative Committee on Introduced Marine Pest Emergencies
CEBO	Chief Environmental Biosecurity Officer
QDAF	Department of Agriculture and Fisheries, Queensland
DAWE	Department of Agriculture, Water and Environment
DPI	Department of Primary Industries, New South Wales
DPIE	Department of Planning, Industry and Environment, New South Wales
DPIPWE	Department of Primary Industries, Parks, Water and Environment, Tasmania
DPIR NT	Department of Primary Industry and Resources, Northern Territory
DPIRD	Department of Primary Industries and Regional Development, Western Australia
EBO	Environmental Biosecurity Office
EPP	Emergency Plant Pest
EPPRD	Emergency Plant Pest Response Deed
GBR	Great Barrier Reef
GMO	Genetically Modified Organism
IGAB	Intergovernmental Agreement on Biosecurity
IUCN	International Union for Conservation in Nature
JCU	James Cook University
NAQS	Northern Australia Quarantine Strategy
NBMG	National Biosecurity Management Group
NEBRA	National Environmental Biosecurity Response Agreement
NESP	National Environmental Science Program
NPBS	National Plant Biosecurity Strategy
NPPP	National Priority Plant Pest
NSW	New South Wales
NT	Northern Territory
PHA	Plant Health Australia
PIRSA	Primary Industries and Regions South Australia
PNG	Papua New Guinea
QLD	Queensland
RoRo	Roll-on/roll-off vessel
SA	South Australia
SARDI	South Australian Research and Development Institute
SNPHS	Subcommittee for Plant Health Surveillance
SPHD	Subcommittee on Plant Health Diagnostics
SWASP	State-Wide Array Surveillance Program
TUMRA	Traditional Use of Marine Resources Agreement
UK	United Kingdom

UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America
Vic	Victoria
WA	Western Australia
WTMA	Wet Tropics Management Authority

EXECUTIVE SUMMARY

Mangrove, saltmarsh and seagrass species are integral components of intertidal and aquatic ecosystems. These plant communities underpin a range of ecosystem functions and industry services. Mangrove and associated communities (saltmarsh and/or seagrass) provide essential habitat and food for a range of sea and shorebirds as well as aquatic animals, including many species of crab, prawn, and fish. Existing on coastal fringes, mangrove communities slow and filter run-off from heavy rain events to improve water quality and stabilise the littoral zone.

Mangrove communities are well recognised for their importance to recreational and commercial fishing activities. At least 75% of recreational and commercial catch fish species are reliant on mangroves during at least part of their life cycle (Australian Institute of Marine Science 2020). By increasing onshore sedimentation mangrove communities also contribute to the stable conditions of many coastal and reef tourist attractions around Australia.

The vital importance of these ecosystems is recognised by the International Union for Conservation in Nature (IUCN). Nineteen percent of global mangrove forests are located within protected areas (Chape et al. 2005). However, these ecosystems remain in danger from a variety of pressures such as climate change, agricultural encroachment, urban development, pollution, extreme weather events as well as pest and disease stressors (Chape et al. 2005).

Increasing international trade and travel heightens Australia's biosecurity risk (McGeoch et al. 2010; Potter et al. 2011, Sikes et al. 2018). Many of Australia's ports are in close proximity to mangrove ecosystems which could increase the likelihood of an exotic pest or disease[1] finding a suitable environment or host and establishing. Furthermore, the processes for responding to environmental pest incursions are less formalised than those within the agricultural sector.

The importance of stakeholder awareness and support in the achievement of successful biosecurity outcomes is well documented (McEntee 2007; Piola and McDonald 2012; Reed and Curzon 2015; Balchin et al. 2018). This may be especially true for remote Australian ecosystems. However, discussions under this project illuminated that engagement of environmental stakeholders on biosecurity issues throughout Australia is limited due to a variety of factors, including differing visions across state, territory and Commonwealth agencies.

This document provides an assessment of the known exotic biosecurity risks to mangrove communities and an overview of the concerns raised by relevant stakeholders. Due to limitations in the literature, a comprehensive risk analysis was not possible. Thus, an approach targeting preparedness activities linked to locations of high-risk for generic pest entry has been proposed. Further, an approach to meaningfully engage stakeholder groups on a local level, complements the targeting of general biosecurity prevention and preparedness activities to high-risk locations. The recommendations provided in this plan are intended to provide governments and stakeholders with a set of prioritised actions for the improvement of biosecurity prevention and preparedness for mangrove communities. However, many of the key gaps identified by this project relate to institutional structures and capacity and community engagement and as such, are largely applicable to improving biosecurity risk mitigation across all environmental taxa. The prioritisation of activities therefore reflects the need to strengthen the environmental biosecurity framework more broadly.

[1] Please note: the definition of "pest" as adopted by the International Plant Protection Convention (any species, strain or biotype of plant, animal, or pathogenic agent, injurious to plants or plant products) is used throughout this document.

For this project stakeholders where those engaged by PHA in the two case studies. The two case studies were selected on the basis of identifying a "tropical" mangrove environment (Cairns's case study) and temperate mangrove environment (Newcastle case study). These two areas were selected as they represent quality examples of mangroves near residential areas, ports, significant environmental protection areas, recreational and commercial fishing areas and are also tourist destinations. For the Cairns case study having a navy base was also a factor. An extensive list of stakeholders contacted and interviewed in each of these case study areas is provided in Appendix 3 and from the PHA preliminary work these locations met the criteria given to PHA in the project scope. They are also a representation of any tropical and temperate mangrove area around Australia.

REVIEW OF FACTORS INVOLVED IN BIOSECURITY FOR MANGROVE COMMUNITIES

BACKGROUND

Working it out, together….

Environmental biosecurity initiatives in Australia have gained momentum with the creation of the Environmental Biosecurity Office (EBO) and appointment of the Australian Chief Environmental Biosecurity Officer (CEBO) within the Department of Agriculture, Water and Environment (DAWE) in 2018. This project was designed to explore how best to approach biosecurity in the native environment by using the 'plant community lens' to assess risks and stakeholder interplay. This community-based approach was employed to capture the foundational role of plants within an ecosystem. Furthermore, addressing threats to discrete taxa may overlook higher-level and/or downstream impacts.

Mangrove forests frequently coexist with saltmarsh and seagrass meadows which together create a highly productive ecosystem of significant ecological value. For the purposes of this document, a mangrove community refers to an ecosystem with one or a mix of mangrove, saltmarsh and/or seagrass species. Saltmarsh in this document, refers to coastal saltmarsh that is tidally influenced and does not include inland saltmarsh.

Improvements to mangrove biosecurity will benefit stakeholders in communities, industries and governments. The agricultural industries have an obvious peak industry body to represent their needs, but no such peak body exists to coordinate the diverse stakeholders of environmental species. Here, governments have stepped in to lead and implement decision making, consulting and engagement with relevant stakeholders as appropriate and where possible. Community and stakeholder support of biosecurity preparedness and response efforts has been repeatedly demonstrated as key to the success of most operations (McEntee 2007; Stefan et al. 2013; Balchin et al. 2018). Passive surveillance of biosecurity threats from members of the community and industry is critical to support the work of government in mitigating biosecurity risk in the natural environment. Engagement of key stakeholders in biosecurity conversations prior to a threat emerging may increase passive surveillance by the public, potentially leading to earlier detection which may increase the effectiveness of an emergency response, should one occur.

The project

This project was designed to highlight some of the gaps relating to the biosecurity protection and management of mangroves, saltmarsh and seagrass communities and to provide a 'roadmap' to address these gaps.

Three case studies were identified to reflect some of the diversity of mangrove ecosystems and social contexts within Australia. The case studies included:

1. Cairns
2. Traditionally owned land between Yarrabah and Black Mountain, North Queensland
3. Newcastle

The selection of these case study sites relates to the mix of environmental, industry and stakeholder contexts within each location. When considered together these case study locations are somewhat representative of

mangrove ecosystems and related stakeholder groups found across Australia.

The key objectives of this environmental risk mitigation plan are to:

1. identify and engage with the stakeholders of the chosen case study sites (stakeholder map provided in attachment)
2. identify the biosecurity risks and risk pathways relevant to mangroves communities
3. investigate risk mitigation options appropriate to the stakeholders of the chosen mangrove case studies
4. provide recommendations to improve biosecurity preparedness for the protection of mangrove communities.

Mangroves

Mangroves are macrophytes that commonly inhabit intertidal areas (between the mean low tide and spring high tide mark) of estuarine and coastal environments. Worldwide there are 70 mangrove species from 20 plant families (Duke et al. 1998). Australia harbors a significant proportion of the known mangrove biodiversity with 41 species from 19 families endemic to Australia (Goudkamp et al. 2006).

Australia has the third largest area of mangroves in the world (Marine Education Society of Australasia 2019) with approximately 6.4% of the global mangrove area (Marine Education Society of Australasia 2019) or an estimated 11,142 ± 57 km^2 (Lymburner et al. 2019). This mangrove area occupies 20% of Australia's coastline (Duke 2006) (Figure 1).

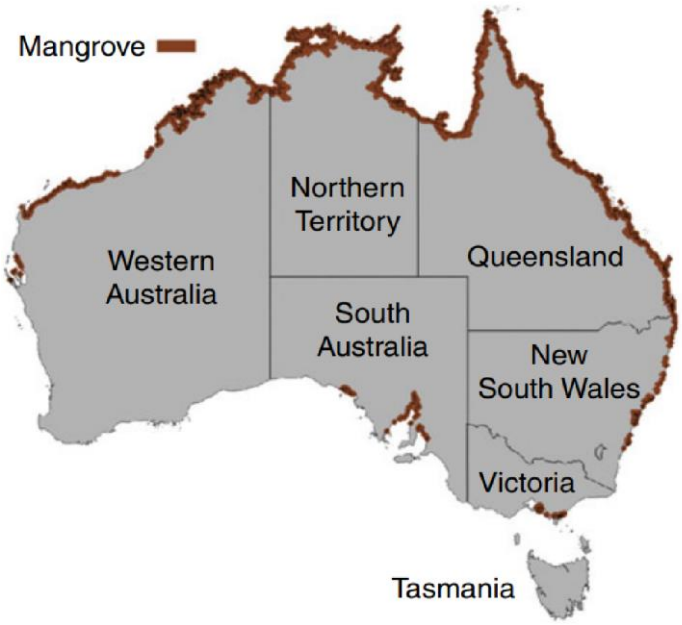

Figure 1: *Australian distribution of mangrove species (source: Serrano et al. (2019)).*

Mangroves grow in a variety of intertidal environments which include deep sheltered bays, exposed beaches, river mudflats and islands. To establish and persist in such environments mangroves possess a range of adaptations including; floating propagules, salt exclusion, salt excretion, buttress or knee roots and pneumatophores.

The most common mangroves in Australia are the red mangrove (*Rhizhophora stylosa*) and the grey mangrove (*Avicennia marina*). *Rhizophora stylosa* is the most common mangrove species in tropical and sub-tropical Australia. *Avicennia marina* is the primary temperate mangrove species and the only mangrove species to grow in Victoria and South Australia (Wells 2006). *Avicennia marina* also grows in tropical and sub-tropical zones and is present in all states and territories where mangroves grow. One endemic Australian species, *Avicennia integra* is found only in the Northern Territory (NT) (Duke 1988) and the endangered Haines orange mangrove (*Bruguiera hainesii)* of which only about 200 plants have ever been recorded globally, was found in 2016 in Trinity Inlet, north Queensland (James Cook University 2016).

Saltmarsh

Saltmarsh communities typically comprise succulents, herbs, sedges and grasses that grow low to the ground in intertidal marine and estuarine sediments. Saltmarsh grow above the mean high tide mark and tolerate intermittent inundation from salt and brackish water (Creighton et al. 2015). Additionally, saltmarsh is dependent on freshwater flushing from rain, river and groundwater flows (Creighton et al. 2015). In Australia, an estimated 13,500 km^2 of saltmarsh grows adjacent to estuaries, floodplains or sheltered beaches; often directly behind mangroves on the coastal gradient (Daly 2013). The distribution of saltmarsh extends to all states and territories within Australia, except for the Australian Capital Territory (Figure 2).

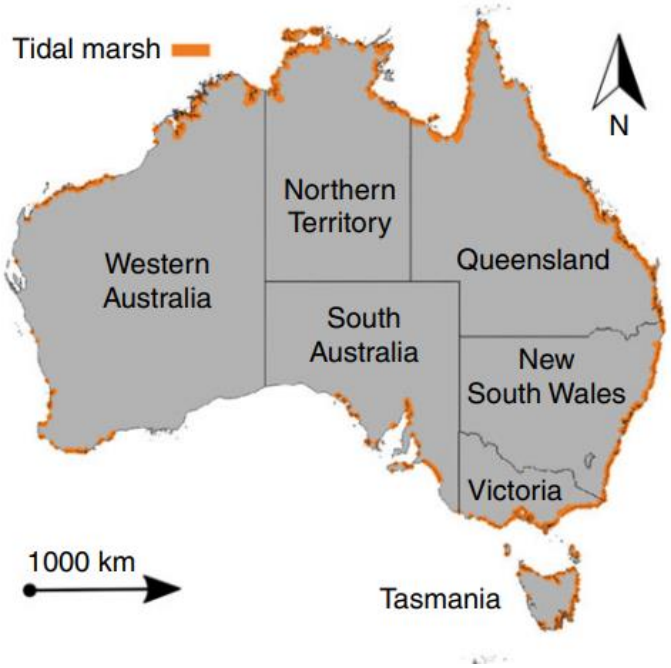

Figure 2: *Australian distribution of tidal marshes (saltmarsh and other herbaceous plant types growing in the intertidal zone) (source: Serrano et al. (2019)).*

Species diversity in the saltmarsh is primarily determined by inundation frequency and salinity. Common saltmarsh species include samphire (*Sarcocornia quinqueflora*), Austral seablite (*Suaeda australia*), shrubby glasswort (*Tecticornia arbuscula*; *Tecticornia halocnemoides*), saltwater couch (*Sporobolus virginicus*), sea rush (*Juncus kraussii*) and bare twig rush (*Baumea juncea*) (Creighton et al. 2015; Daly 2013).

Seagrass

Seagrasses are aquatic plants often with ribbon-like leaves that grow in shallow subtidal or intertidal zones. To allow them the flexibility required to withstand tidal currents, seagrasses are generally low in lignin, while their strong stabilising rhizomes anchor them in soft sands and sediments.

Seagrass colonisation and meadow dynamics involve sexual propagules, clonal propagation and vegetative fragmentation (Short et al. 2001). There are approximately 51,000 km^2 of seagrass meadows fringing Australia's coastline (Marine Education Society of Australasia 2020) in subtropical (38%), tropical (32%), arid (16%) and temperate (14%) climatic regions (Serrano et al. 2019) (Figure 3).

Figure 3: *Australian distribution of seagrasses (source: Serrano et al. (2019)).*

Globally there are 57 species of seagrass, 33 of which grow in Australia (Marine Education Society of Australasia 2020). Species diversity is higher in tropical and sub-tropical waters, with the waters surrounding the Great Barrier Reef (GBR) demonstrating Australia's greatest diversity of seagrass (Coles et al. 1993).

Depth, water turbidity, sediment composition, water temperature and current all affect seagrass species range. Common Australian seagrass species include the hairy spoon seagrass (*Halophila decipiens*), eelgrass (*Zostera capricorni*), *Amphibolis griffithii*, *Halodule pinifolia*, fern seagrass (*Halophila spinulosa*) and sickle seagrass (*Thalassia hemprichii*) (Marine Education Society of Australasia 2020). *Posidonia australis* is the dominant seagrass in southern Australia.

Mangrove communities and the environment

Regarded as the kidneys of their ecosystem, mangrove communities are integral to the healthy functioning of a large number of estuarine, coastal and off-shore habitats. Mangrove communities filter and purify the water run-off from floodplains and rivers and the tree roots reduce bank erosion and increase inshore sedimentation (Coles et al. 1993; Alongi 2002).

Coastlines covered by mangrove communities have increased resilience against extreme weather events like cyclones and rising sea levels (Zhang et al. 2012). The dense community of plants stabilises the shoreline, protecting it against erosion and inundation (Lee et al. 2014). Mazda et al. (1997) calculated that wave energy is reduced by 20% for every 100 m depth of mangrove forest (taken from open water). The Global Commission on Adaptation estimated that every dollar spent on protection of mangroves could yield upwards of five dollars in climate change adaptation and resilience benefits (Global Commission on Adaptation 2019). In light of the predicted increase in extreme storm events and rising sea levels, the importance of mangrove communities in protecting and maintaining our ecosystems and way of life will only increase.

Mangrove communities provide essential refuge and habitat for an abundance of terrestrial, aquatic and bird life. Mangroves are vital nurseries for fish (including the sea mullet, mangrove jack, barramundi), prawn, saltwater crocodiles, lizards, snakes, bats and flying foxes (Lee et al. 2014; Spalding and Parrett 2019). Moreover, saltmarsh is an important breeding area for prawns, fish and crabs and a critical habitat for shore and seabirds like the sharp-tailed sandpiper and marsh sandpiper.

Seagrass communities act as a nursery for smaller animal species and provide the habitat for a range of aquatic species including mullet, cow tail rays, eagle rays, Port Jackson sharks, red swimmer crabs, leatherjackets and sea snakes. A study of the fish density in seagrass meadows near Cairns Harbour found the density of fish to be 8809 ha^{-1} and comprised of 134 taxa (Coles et al. 1993). Each intertidal and aquatic plant community is central to the maintenance of ecosystem composition, structure and function.

The breakdown of detritus produced by decaying saltmarsh, seagrass and mangrove provides nutrients which support populations of phytoplankton, the foundational component of the range of marine food chains (Coles et al. 1993). The process of anaerobic organic matter breakdown also contributes to the productivity of mangrove communities in sequestering carbon from the atmosphere. Though mangrove and seagrass communities cover only around 1% of the seafloor, they are responsible for sequestering 70% of the carbon in the marine environment (Marine Education Society of Australasia 2019). Recent research by Serrano et al. (2019) found that Australia contributes 5 to 11% of the global carbon that is annually stored in vegetated coastal ecosystems.

Mangrove communities also hold significant cultural and functional value to Indigenous Australians. Mangrove communities are important hunting and fishing grounds and are a source of bark tannin which is used to make dyes (Bandaranayake 1998). Mangrove wood is used to make boomerangs, canoes and paddles and ashes from the yellow mangrove (*Ceriops australis*) and the kapok mangrove (*Camptostemon schultzii)* are used to treat sores and infections (Duke 2006). Seagrasses are an essential food source for endangered dugong and turtles. These animals hold great cultural significance for Indigenous Australians in the north of the country. Mangroves continue to be important places for cultural and recreational use.

Mangrove communities and industry

Mangrove communities are crucial nursery grounds for many aquatic species that are commercially harvested. Around two-thirds of commercially caught fish are dependent on mangrove communities at some point in their lives (Department of Environment and Energy 2016). Fishing and aquaculture industries are worth $5.3 billion to the Australian economy annually, a large proportion of which is derived from the export market which relies heavily on prawns (Fisheries Research and Development Corporation 2019). In 2017-18 the Australian fishing and aquaculture industries supported 41,254 jobs (Fisheries Research and Development Corporation 2019).

Australia's recreational fishing industry is worth approximately $2.2 billion with 3.4 million Australians participating on an annual basis (Colquhoun and Ridge Partners 2015). Robertson and Blaber (1992) reported that fish species diversity in Australian waterways adjacent to mangroves was almost 200 species. Jänes et al. (2020) found that one hectare of Australian seagrass beds supported 55,000 more fish in a year than unvegetated seabeds. This contributes AUD$21,000 per hectare to commercial fisheries each year. The same study found that one hectare of mangroves supported 19,000 more fish than an unvegetated seabed, while one hectare of tidal marshes supported 17,000 more fish than an unvegetated seabed (Jänes et al. 2020).

Important commercial and recreational aquatic species that use mangrove communities as nursery grounds include yellowfin bream (*Acanthopagrus australis*), dusky flathead (*Platycephalus fuscus*), sand whiting (*Sillago ciliate*), sea mullet (*Mugil cephalus*), garfish (*Arrhamphus sclerolepis*), mulloway (*Argyrosomus japonicus*), King George whiting (*Sillaginodes punctatus*), mud crab (*Scylla serrata*), school prawn (*Metapenaeus macleayi*), banana prawn (*Penaeus merguiensis*) and western school prawns (*Metapenaeus dalli*) (Daly 2013; Creighton et al. 2013; Jänes et al. 2020).

Mangrove communities support tourism and recreational activities such as hiking, boating, fishing and bird-watching. A 2019 study of global patterns of mangrove recreation and tourism identified 279 Australian mangrove tourist attractions listed on TripAdvisor (Spalding and Parrett 2019). There were 57,229 reviews of the Australian mangrove tourist attractions, which equated to 57% of global mangrove tourist attraction reviews (Spalding and Parrett 2019). These identified mangrove tourist attractions were distributed throughout the mangrove growing areas of Australia (Figure 4).

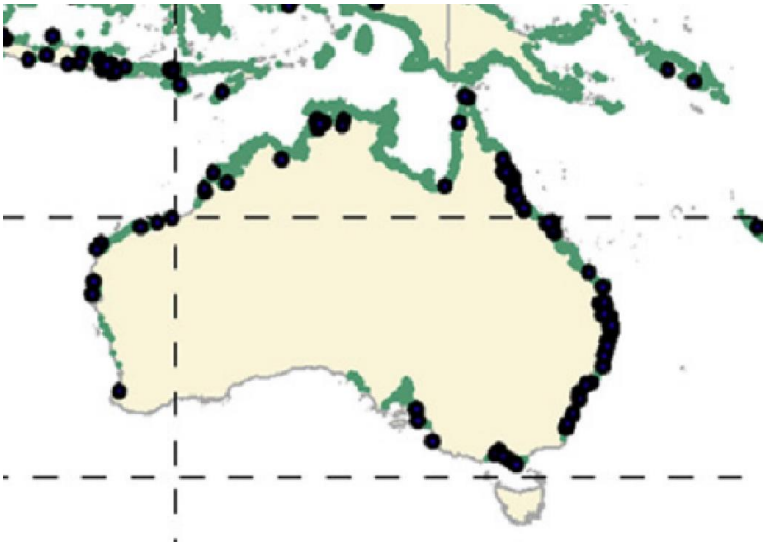

Figure 4: *Australian distribution of mangrove toursist and recreational attractions (back dots) over mangrove area (green) (source: Spalding and Parrett 2019).*

Bird watching is another important recreational and ecotourism activity which attracts international and domestic tourists to regional areas of Australia. Mudflats which are often a combination of mangrove, seagrass and/or saltmarsh areas provide major feeding grounds for migratory waders and seabirds. Recent surveys found that mangrove forests provide habitat for at least 230 species of bird and a survey of the Tasmanian saltmarshes identified 113 bird species (Prahalad et al. 2015).

Superyacht and cruise tourism stakeholders also hold concerns for marine biosecurity as a matter of economic importance and business sustainability. The establishment of a marine pest at a popular destination would have negative effects on the destination. Itinerant vessels are likely to avoid ports with marine pests because time spent in such ports would label them high risk at subsequent ports and may cause additional biosecurity measures to be placed on them.

Accumulating pressures on mangrove communities

Mangroves are now among the most threatened ecosystems in the world. Between 1990 and 2000, it was estimated that mangrove communities were being lost at rate of 1% per year; double the proportional rate of terrestrial rainforests. Increased pressures from urban development, climate change and land clearing have impacted mangrove communities and it has been estimated that 38% of mangrove areas were directly affected by human activities between 1996 and 2010 (Thomas et al. 2017).

Owing to their location on high-value, waterfront land, mangrove and saltmarsh populations are increasingly threatened by urban development. In addition to requiring the removal of mangrove stands, the construction of coastal esplanades and waterfront properties acts as a barrier to the natural movement of mangrove populations up the coastal gradient as sea levels rise. This constriction of habitat between sea level and urban developments is also a major contributor to saltmarsh decline because mangroves encroach on the saltmarsh and the saltmarsh are prevented from upland migration (Herbert 2007).

Mangrove communities are persistently undervalued and threatened by a range of anthropogenic activities (Department of Environment and Energy 2016). Historically, saltmarsh and mangrove sites have been used as rubbish dumps or have been reclaimed and filled in for sports fields, marinas and urban and industrial development. Eutrophication from urban and industrial run-off and oil spills threatens mangrove communities, especially when natural tidal movements are altered through the construction of canals or flood gates. Alteration of the natural tidal movements prevents the flushing out of chemical build-up from within mangrove communities and changes the extent of conditions favorable for mangrove community growth (Creighton et al. 2013).

Boat traffic and anchors disturb mangrove communities through wave action and mechanical damage. Chains from boat moorings scour the seafloor, damaging and ripping up seagrass meadows (La Manna et al. 2015). Dredging also destroys seagrass beds by removing the sediments in which they grow and increasing water turbidity. Degradation by cattle and vehicles, competition with invasive weeds, mowing and trampling by humans are also major sources of decline of Australian mangrove and saltmarsh populations (Daly 2013).

Environmental processes such as climate change and sea level rise pose additional threats to mangrove communities (Daly 2013). Fluctuations in temperature and extreme climatic conditions, including storms and cyclones, have significantly contributed to the loss of mangrove extent in Australia (Lymburner et al. 2019). Aerial surveys by Duke and Mackenzie (2018) identified 400-600 ha of severely damaged mangroves near the Starcke River in 2017 which they deemed to be the likely result of Tropical Cyclones Ita and Nathan. Additionally, these aerial surveys identified the principal drivers of change in mangrove forests on the eastern side of the Cape York Peninsula to be climatic/natural threats. In contrast, the stretch of mangrove forests between the more southerly Mowbray and Endeavour Rivers were reported to be predominantly impacted by anthropogenic drivers of change such as alterations to hydrology, feral pigs, agricultural encroachment and cattle and vehicle damage (Duke and Mackenzie 2018).

In general, frontal erosion, terrestrial retreat and storm damage were the environmental processes which caused the most considerable impact on the stretch of coastline from Cairns to the 'tip' of Cape York (Duke and Mackenzie 2018). The human associated drivers of change that were reported to have had the biggest impact on mangrove and saltmarsh communities on the same stretch of coastline were cattle grazing, feral pigs, altered hydrology and vehicle damage (Duke and Mackenzie 2018).

The accumulation of these pressures and their subsequent impact on the rate of change of mangrove communities is evident. Threats to mangrove communities should therefore be considered in the wider context of these accumulating pressures in order to properly weigh up the risk to mangrove health and survival.

Mangrove community stakeholders

Like many other natural resources, mangrove communities serve a variety of productive and ecological functions. Subsequently, there are a diverse group of relevant stakeholders with an equally wide range of available knowledge and resources as well as geographic and access constraints. Stakeholders must be appropriately considered in risk mitigation planning to ensure policy and prevention activities are relevant, suitable and effective.

A list of stakeholders and their interactions with mangrove communities for this project's three case study locations (Cairns, Newcastle and traditionally owned land between Yarrabah and Black Mountain) has been provided in a separate document '*Mangrove community stakeholder and case study analysis*.'

RISK MITIGATION PLANNING FOR MANGROVE COMMUNITIES

Australia's geographic isolation and lack of shared land borders has provided a degree of natural protection from exotic plant pest threats. Australia's national biosecurity system also helps to limit the introduction of harmful exotic pest threats to plant industries and the environment. However, there will always be some risk of an exotic pest entering Australia, through wind or current assisted natural dispersal, inadvertent introductions as a result of increases in international tourism, imports and exports, mail, and changes to transport procedures (e.g. refrigeration and containerisation of produce), or deliberate introduction of materials for personal use. Therefore, activities to reduce biosecurity risk and increase biosecurity preparedness are increasingly important.

The agricultural industries have well developed processes, supported by peak industry bodies and government structures, to minimise the risks posed by exotic pests. This includes the development of industry-specific Biosecurity Plans which provide a mechanism for industry, governments and stakeholders to identify opportunities for systemic improvements which enhance biosecurity preparedness and mitigate risk. Biosecurity response processes for the environment are managed by the inaugural Chief Environmental Biosecurity Officer (CEBO) who was appointed in 2018. Prior to the creation of the Environmental Biosecurity Office (EBO), biosecurity activities and emergency response processes were managed by the Australian Chief Plant Protection Office (ACPPO) or Australian Chief Veterinary Office (ACVO).

Recent work has identified the need for increased activity and resourcing to support biosecurity for the environment. Aichi Biodiversity Target 9 for signatories to the Convention on Biological Diversity requires that 'invasive alien species and pathways are (i) identified and prioritised; (ii), priority species are controlled or eradicated, and (iii) measures are in place to manage pathways to prevent their introduction and establishment' (Convention on Biological Diversity 2020). Additionally, the Inspector-General's Review of Environmental Biosecurity Risk Management in Australia recommended that the government 'work with stakeholders to contribute to the development of environmental biosecurity plans targeting specific pests and diseases aimed at environmental sectors of concern, and include the community as much as possible' (Inspector-General of Biosecurity 2019).

Risk mitigation planning looks at procedures to reduce the risk of pests of mangrove communities entering the country. Additionally, preparedness activities increase the likelihood that an incursion would be detected in a timely manner to improve the chances of reducing the ecological, social and economic costs associated with exotic pest incursions and spread within mangrove communities.

The environmental biosecurity system

Management of environmental biosecurity risks to Australia is provided for under the *Biosecurity Act 2015* and the *Environment Protection and Biodiversity Conservation Act 1999* legislation. The framework for delivery of Australia's plant biosecurity system is built on a range of strategies, policies and legislation, such as the Intergovernmental Agreement on Biosecurity (IGAB), the National Plant Biosecurity Strategy (NPBS) and state biosecurity legislation including the General Biosecurity Obligation (QLD) and the General Biosecurity Duty (NSW and Tas).

These strategies, policies and legislation provide details about the current structure and responsibilities for management of biosecurity activities and outline a vision of how the future plant biosecurity system should operate.

Australia has a unique and internationally recognised biosecurity system to protect our plant production industries and the natural environment against new pests and diseases. The system is underpinned by a cooperative partnership between plant and animal industries, environmental stakeholders, the general public and all levels of government. Effective biosecurity relies on commitment from all stakeholders (Figure 5).

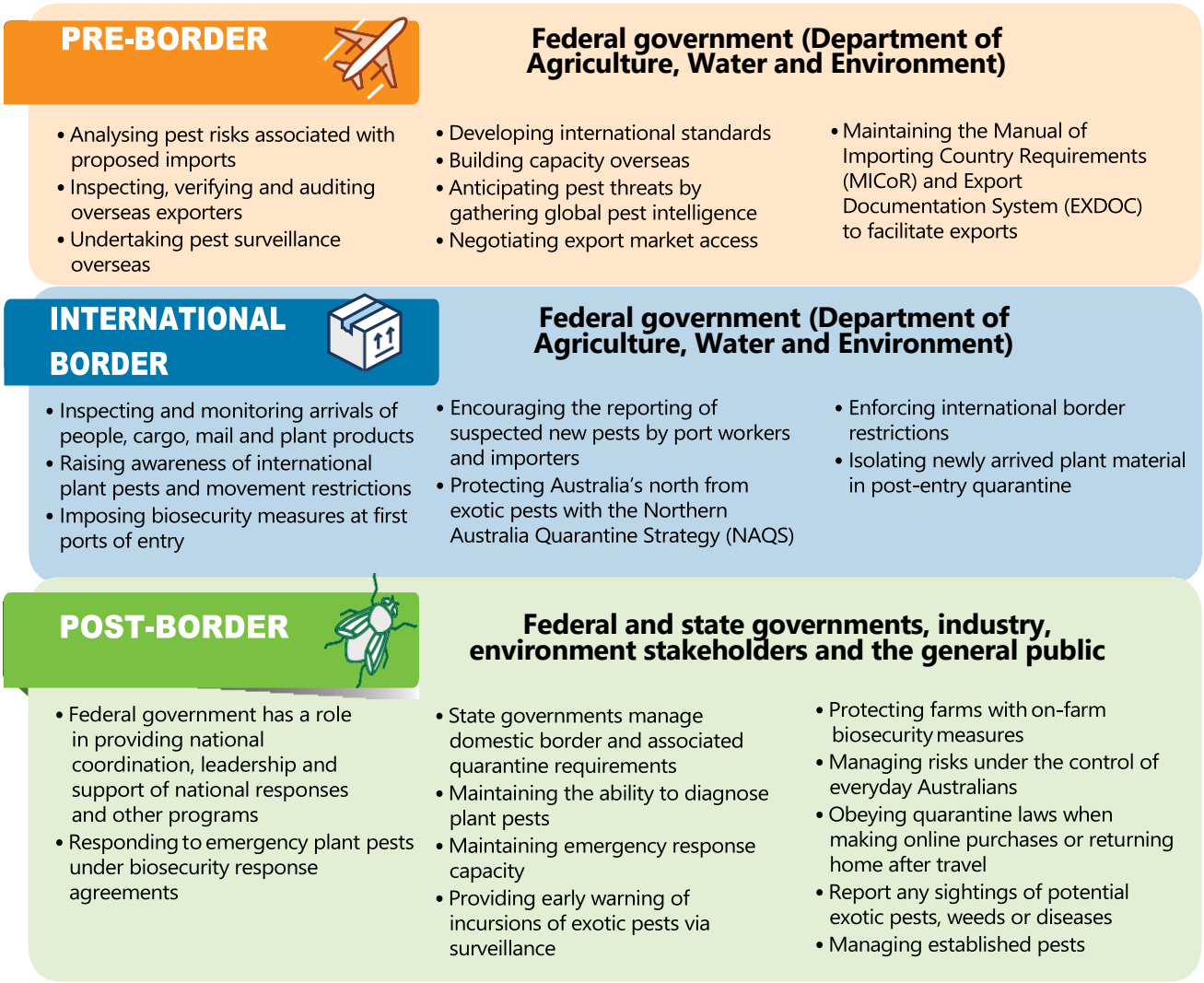

Figure 5: *Biosecurity: a shared responsibility.*

The Environmental Biosecurity Office (EBO), led by the CEBO within DAWE, is working to strengthen Australia's environmental biosecurity system, including by investing in improving preparedness and response activities for pests and diseases that affect the Australian environment. The CEBO is also the national point of contact for notification of environmental biosecurity incursions under the National Environmental Biosecurity Response Agreement (NEBRA). The EBO facilitates improved relationships with environmental stakeholder groups and ensures that consideration of the environment is forefront in national biosecurity planning discussions.

DAWE plays a key role pre-border, working with exporting nations to minimise risks before product leaves a country and manages the international border, where the movement of people and goods are regulated. These activities aim to prevent entry and establishment of exotic pests and diseases.

The Australian Biosecurity Import Conditions (BICON) database at agriculture.gov.au/bicon contains the current Australian import conditions for more than 20,000 foreign plants, animal, mineral and biological products and is the first point of access to information about Australian import requirements for a range of commodities, including mangrove, saltmarsh and seagrass products.

BICON can be used to determine if a commodity intended for import to Australia requires a biosecurity import permit and/or treatment or if there are any other biosecurity prerequisites. DAWE regularly review import conditions and where new information becomes available the import conditions are modified appropriately. To search BICON conditions relating to a particular commodity visit https://bicon.agriculture.gov.au/BiconWeb4.0.

Within Australia, post-border biosecurity measures aim to prevent the spread of regionalised weeds, pests and diseases, and to contain and eradicate any new pest that may enter Australia.

Post-border biosecurity relies on the activities of federal government, state governments, local governments, property owners and everyday Australians to manage existing threats, report any suspected new pests and obey quarantine laws.

Biosecurity response framework

There are two existing arrangements that could be used to respond to an exotic pest incursion affecting mangrove, seagrass or saltmarsh species. The arrangement applied depends on the pest detected. If the plant pest meets the definition of an Emergency Plant Pest as defined by the Emergency Plant Pest Response Deed (EPPRD), then this deed would apply. If the pest is not considered to meet the definition of an Emergency Plant Pest under the EPPRD and the pest has the potential for impacts on the environment, social amenity or business activity and otherwise meets the requirements of the NEBRA then that agreement may apply.

The Emergency Plant Pest Response Deed

The EPPRD is an agreement between the Australian government, the state and territory governments, 38 plant industries and Plant Health Australia (PHA) (collectively known as the signatories), that allows the rapid and efficient response to Emergency Plant Pests (EPP). The EPPRD is a legally binding document that outlines the basic operating principles and guidelines for EPP eradication responses[2].

The EPPRD provides:

- a national response management structure that enables all governments and plant industry signatories affected by the EPP to contribute to the decisions made about the response
- an agreed structure for the sharing of costs to deliver eradication responses to EPPs detected in Australia. Costs are divided between signatories affected by the EPP in an equitable manner based on the relative public/private benefit of eradication of the EPP
- a mechanism to encourage reporting of EPP detections and the implementation of risk mitigation activities
- a mechanism to reimburse growers whose crops or property are directly damaged or destroyed as a result of implementing an EPP Response Plan
- rapid responses to EPPs
- a framework for decisions to eradicate are based on appropriate criteria (e.g. eradication must be technically feasible and cost beneficial)

[2] For further information on the EPPRD visit planthealthaustralia.com.au/epprd.

- an industry commitment to biosecurity and risk mitigation and a government commitment to best management practice.

The current version of the EEPRD is available at planthealthaustralia.com.au/epprd.

The National Environmental Biosecurity Response Agreement

The NEBRA establishes the national arrangements for responding to significant pest and disease incursions that impact the environment, social amenity and business activity, where there are predominantly public benefits. The NEBRA was signed in 2012 by state, territory and Commonwealth governments. Funding a response under the NEBRA is the responsibility of government with, 50% contributed by the Commonwealth and the remaining 50% shared by affected state and territory governments.

The NEBRA includes a clause which indicates that if an emergency response to a pest or disease can be handled under existing cost-sharing arrangements (such as the EPPRD) the parties will agree to manage it under those existing arrangements. If the pest does not meet the Emergency Plant Pest definition outlined above or other existing national cost-sharing arrangements, then the response may be eligible for eradication under the NEBRA.

A copy of NEBRA is available from coag.gov.au/sites/default/files/agreements/National-Environmental-Biosecurity-Response-Nov-2012.pdf.

Some important biosecurity considerations for mangrove communities

Natural pathways

When considering the biosecurity of mangrove communities, it is important to note that the natural movements of driftwood, coconuts and propagules on ocean currents over time has likely exposed mangroves (at least in Australia's north) to endemic insect and microbial species of nearby countries. Additionally, Indigenous Australians traded with the Macassan people of Indonesia on an annual basis since at least 1650 (though some scholars argue that this relationship could be closer to 1,000 years old) (Griffiths 2018). These arrivals could have facilitated the translocation of mangrove community pests.

Further, Australia was joined to New Guinea and Indonesia up until at least 20,000 years ago, and New Guinea until 9,000 years ago (Monash University 2007). This land connection has existed at multiple times over relatively recent geological history (Monash University 2007) so it is likely that many of the mangrove pests are shared between these countries, or share an evolutionary ancestor. Therefore, it may be that the bigger risk to Australian mangrove communities via natural pathways is from pests that switch hosts or that change their behaviour under changed environmental conditions such as climate change or lack of other suitable hosts, or if the pest status in these countries change.

Rhizophora spp. are the dominant tropical and sub-tropical mangrove genus in northern Australia and worldwide (Figure 6). Hence, much of the northern coastline of Australia has the appropriate conditions and available host(s) for establishment of exotic pests of *Rhizophora* spp.

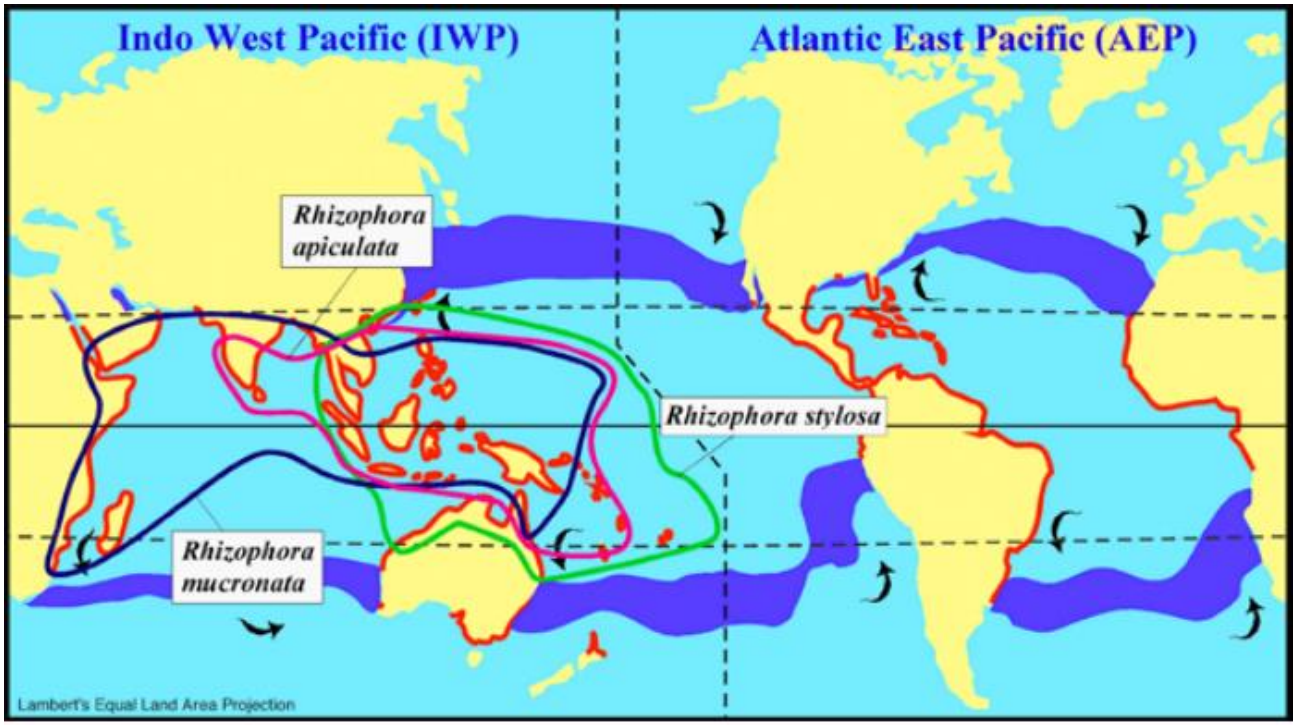

Figure 6: *Global distribution of common Rhizophora mangrove species. Green line = R. stylosa, pink line = R. apiculata, blue line = R. mucronata, red line = distribution of all mangrove species (image sourced from Duke 2006).*

The translocation of pests on marine debris is a recognised pathway. NAQS have previously undertaken surveys of driftwood on the coasts of northern Australia and established the potential for marine pests (e.g. Asian green mussels) and termite and borer pests to enter via this pathway. DAWE partner with Tangaroa Blue, an Australian organisation which coordinates marine debris clean-ups. Tangaroa Blue collect data about biosecurity risk materials and report any pest concerns that are associated with marine debris.

Import pathway

There is no evidence supporting the importation of mangrove propagules or seedlings for revegetation projects in Australia. Australian mangrove revegetation projects have secured stock through contracts with local nurseries and engagement of volunteer and ranger groups for the collection and propagation of mangrove seedlings.

There is some incidence of mangrove-related imports into Australia, mostly mangrove wood charcoal and mangrove root, most likely for the aquarium trade. Websites such as 'eBay' and 'Etsy' sell mangrove seeds online from places such as the United States, Guadeloupe and India. Mangrove seedlings are advertised as an aquarium plant and accessory. It is up to the discretion of the seller as to whether they will ship goods to Australia without going through the appropriate import declaration process. There is some potential risk that small purchases of mangrove products made online and sent through the mail may not be declared or detected on arrival.

Nine of the 31 mangrove and saltmarsh plant pests identified as exotic to Australia had alternative, non-mangrove hosts. This indicates the potential for mangrove pest entry in the importation of other plant material. *Acacia*, coffee, mango and other woody plants are documented as alternative hosts for mangrove pests.

Biosecurity experts indicate that the illegal aquarium, pet and restaurant trade is a high-risk pathway for exotic aquatic pests. Australian mail exchanges commonly intercept shipments of live crabs and aquatic species such as the Chinese mitten crab, Asian paddle crab and ghost crab intended for use in restaurants or for breeding. Turtles and tortoises, lizards and other small animals are also commonly intercepted through the mail exchange.

An additional risk for aquatic invasive species may come from the importation or purchase of other risk items such as second-hand boats and kayaks, food destined for consumption used as bait, food or other waste from boats disposed of at sea or in the harbour or the intentional or unintentional release of aquatic species aquired through the aquarium trade.

Hitchhiking on vessels or airplanes

There are 31 international airports in Australia, 7 of which are classified as major international airports (Adelaide, Brisbane, Cairns, Darwin, Melbourne, Perth, Sydney) and the remaining classified either as restricted use, alternate, non-scheduled or external territory. Of the seven major international airports, four are in close proximity to mangroves and could potentially facilitate mangrove pest establishment (Brisbane, Cairns, Sydney, Darwin)[3]. Of the 24 non-major international airports, 10 are in close proximity to mangrove populations[4].

Being an island nation, sea transport is crucial to Australian industries. Over 95% of Australia's imports and exports are currently transported by sea (Piola and McDonald 2012). In 2014-15, 5,475 cargo ships made 29,595 calls to Australian ports (Bureau of Infrastructure, Transport and Regional Economics 2017). This

[3] As determined by PHA through google satellite imagery, google street view and destination images.
[4] Broome, Coffs Harbour, Gold Coast, Learmonth, Newcastle, Port Hedland, Sunshine Coast, Townsville, Horn Island, Cocos (Keeling) Island.

included 5,387 cargo ships, which made 16,556 voyages to Australian waters directly from overseas ports (Bureau of Infrastructure, Transport and Regional Economics 2017).

First ports of entry are approved ports for vessels arriving directly from international destinations where facilities exist for processing and quarantine inspection. There are 58 first ports of entry in Australia (Department of Agriculture, Water and Environment 2020b), 31 of these are in close proximity to mangroves[5]. Vessel transit times have been decreasing which may increase the risk of hitchhiking pests surviving transit. For instance, vessels travelling to Australia take 10-14 days from China and 22 days from the east coast of the United States. If a mangrove pest is able to hitchhike and survive these transit times then it may be possible for them to find suitable hosts and establish at these ports.

Figure 7 (below) displays all (reporting) vessels in Australian and international waters on Wednesday, 30th October 2019 and demonstrates the significance of sea traffic at any given time.

Figure 8 illustrates the considerable frequency of vessel movements in Australian waters throughout the year. This data is reported by marine traffic.com and uses vessel satellite reporting to track movements.

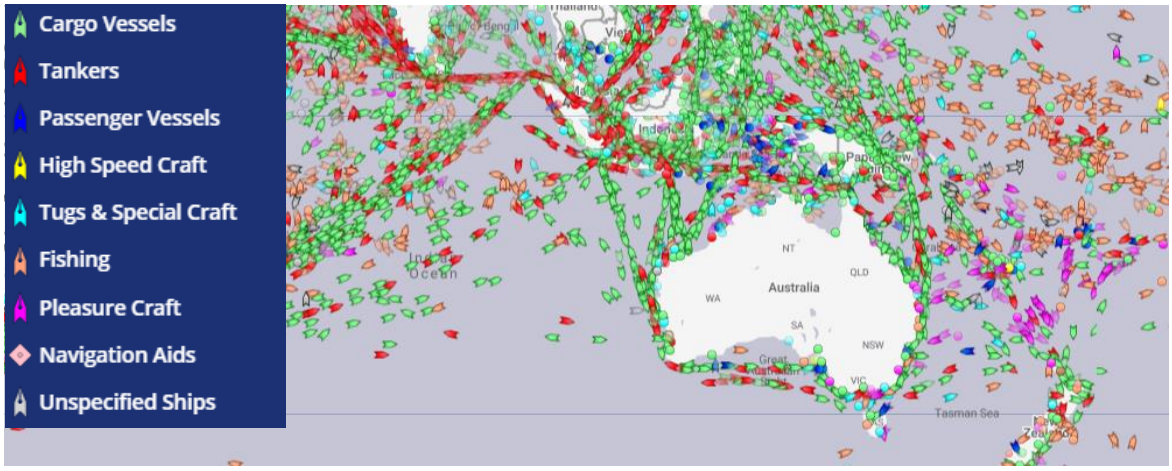

Figure 7: *Sea vessel traffic reporting position via satellite on Wednesday 30th October 2019 (Source: Marine Traffic 2019).*

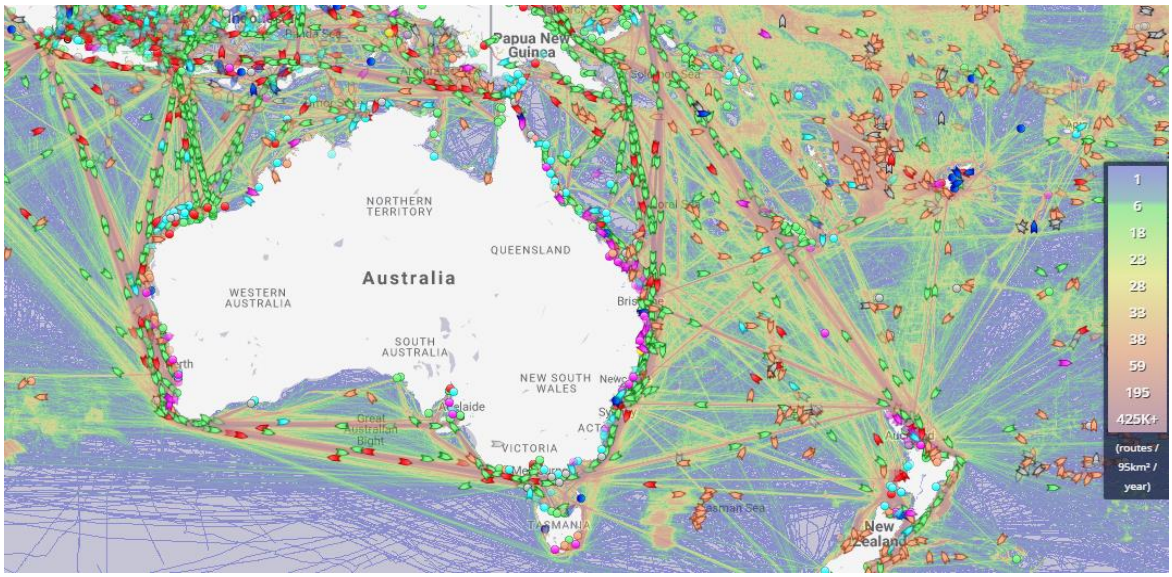

Figure 8: *Cumulative frequency of sea traffic routes. Red= travelled over 425,000 per year (source: Marine Traffic 2019).*

[5] As determined by PHA through google satellite imagery, google street view and destination images. Australia's first ports of entry determined to be in close proximity to mangroves are; Coffs Harbour, Newcastle, Port Botany, Sydney, Eden, Yamba, Darwin, Melville Bay, Bowen (Abbot Point), Brisbane, Bundaberg, Cairns, Gladstone, Gold Coast Broadwater, Hay Point, Lucinda, Mackay, Mourilyan, Port Alma, Port Kennedy, Townsville, Weipa, Port Pirie, Broome, Bunbury, Dampier, Derby, Port Hedland, Port Walcott, Wyndham, Cocos (Keeling) Islands.

The incidence of abandoned fishing vessels and other vessels along the coastline is thought to have significantly decreased over recent years. Over the past decade, NT DPIR received 11-20 reports of illegal abandoned vessels each year but in recent times this has dropped sharply (2 in 2019).

Vessels used to transport illicit substances are sometimes abandoned on the Australian coastline, often between Yamba and Coffs Harbour, but these tend to be low risk for plant and animal material and the incidence is around one per year.

Ballast water

Ballast water is pumped into ballast tanks to stabilise and counterbalance vessels when the load is insufficient or is unevenly distributed. Vessels may need to take in or release ballast water before transporting goods and/or travelling to another port. As a result, ballast water has been responsible for the translocation of many marine pests around the world including the European zebra mussel in North America, the northern Pacific sea star in Australia, North and South America, Japan and South Africa and the zebra mussel in North America (Tennessen 2020). Vessels in Australian waters must manage ballast water in accordance with the Australian Ballast Water Management Requirements (Department of Agriculture, Water and the Environment 2020a). Vessels are encouraged to use low-risk ballast water (e.g. fresh potable water, high seas water or fresh water from an on-board production facility) or to use a Ballast Water Management System which does not require ballast water exchange. Though vessels over 500 t are not permitted to release ballast water onshore, there are circumstances in which this is unavoidable, such as staff and safety emergencies.

Newly introduced regulations also exist for domestic ballast water management. Vessels leaving particular Australian ports must manage ballast before entering other Australian ports. These regulations are aimed at preventing the spread of particular invasive marine species that are not widely distributed around Australia.

Biofouling

Biofouling is the accumulation of marine life, including bacteria, algae, cysts and the eggs and larvae of various marine species which attach to the underwater components of vessels. Biofouling is a recognised pathway for the translocation of marine pests around ports of the world. Biofouling is managed through regular cleaning and application of anti-fouling treatments as outlined by the National Biofouling Management Guidelines (Department of the Environment and New Zealand Ministry for Primary Industries 2015). This requires either in-water cleaning or bringing the vessel onto the slipway for cleaning and treatment applications. Some of the toxic chemicals used in anti-fouling treatments may be phased out in favour of other technologies as they are developed (Brett Herbert and Cian Foster-Thorpe pers. comm., 2019).

Generally, commercial vessels have good anti-biofouling practice because fouling slows vessels and increases fuel costs. The navy adhere to high standards in biofouling practice and use divers or autonomous underwater vehicles (AUVs) for the surveillance of marine pest presence on their hulls. Vessels such as superyachts and other recreational vessels which travel from country to country are the highest risk for biofouling because they stay at port longer, allowing greater time for fouling colonisation and may have poorer adherence to anti-fouling practice. These vessels travel up and down the Australian coast, often looking for remote locations to moor, increasing the chances for spread.

DAWE undertakes a risk assessment of each vessel arriving into Australia to assess what biosecurity inspections or measures are necessary to mitigate risk. The Maritime Arrivals Reporting System requires vessels to declare their last 10 ports of call and the time spent at each to assist the assessment. Vessels deemed to be an unacceptable risk may be required to be removed from the water, inspected and if necessary, treated. Passive and active surveillance for marine pests occurs in locations around Australia at the discretion of state/territory agencies.

THE RISKS

Pest risks

A review of the literature was conducted to develop a list of 31 exotic pests and diseases that negatively impact either mangroves, saltmarsh or seagrass species (Table 1). There were a number of challenges in the development of this list. For instance, available information on saltmarsh and seagrass pests was limited. Additionally, the taxonomic understanding and precision used to identify mangrove pests requires further inquiry to adequately describe risks and pathways. These challenges are discussed on page 31.

The list of plant pests in Table 1 includes any insect, disease or arthropod reported to affect mangroves, saltmarsh and seagrass of any species (not only those present in Australia) but does not include pests described only to family rank. Subsequently, the list of exotic pests of mangroves, saltmarsh and seagrass is an underestimate of the true diversity of pest threats. Further, the impact of each detrimental organism cannot be accurately determined without further study. Therefore, this list should be considered as a representative example (rather than a comprehensive list) of pests that affect mangrove communities that can be used to assist in pest risk and pathway analysis.

A list of 5 representative invasive marine pests which may survive in Australian mangrove communities was also considered (Table 2). The inventory of exotic pests that can survive in mangrove communities is extensive. For this reason, this project considered only the pests identified as significant invasive marine pests of concern to the environment according to the Priority List of Exotic Environmental Pests and Diseases (the Priority List) and only those which can survive in mangrove communities. These invasive environmental pests were considered in a representative way to facilitate pathways discussion on the types of pests that are most likely to enter and establish in these ecosystems and result in serious negative consequences to the environment.

Table 1: *Exotic pests and diseases reported to affect mangrove, saltmarsh or seagrass species overseas.*

SCIENTIFIC NAME	COMMON NAME	FAMILY	DISTRIBUTION	MANGROVE AND OTHER HOSTS
			INVERTEBRATES	
ARCHAEOPULMONATA				
Melampus coffeus	Coffee bean snail	Ellobiidae	United States of America (USA), South America, Central America, Caribbean	Mangroves; *Rhizophora* spp., *Laguncularia* spp., *Avicennia* spp.
COLEOPTERA				
Bottegia rubra		Cerambycidae	South Africa, Kenya, Tanzania	Mangrove (*Sonneratia alba*)
Coccotrypes rhizophorae	Rhizophora root borer	Curculionidae	Singapore, Myanmar, USA, Mexico, Ecuador, Peru, Suriname, Caribbean	*Rhizophora* sp., *Acacia*, langsat (mahogany family)
Elaphidion mimeticum		Cerambycidae	Central America, USA	Mangrove (*Rhizophora* sp., *Avicennia* sp.)
Elaphidinoides sp.		Cerambycidae	USA, South America	*Rhizophora mangle* (Red mangrove)[6]
Euwallacea xanthopus	Ambrosia beetle	Curculionidae	India, Nigeria, Tanzania, Uganda, Kenya, South Africa, Democratic Republic of the Congo, Madagascar, Côte d'Ivoire, Thailand, Philippines, Myanmar, Fiji, Indonesia, Sri Lanka, Malaysia	Common ivy palm, jack fruit, cabbage tree (*Cussonia* sp.), quinine tree (*Rauvolfia caffra*), flame tree, *Dyera costulata*, *Eugenia* sp., *Fauchera* sp., *Ficus* sp., *Gouania glandulosa*, *Hibiscus macrophyllus*, *Maesa lanceolate*, *Mangifera indica*, *Pittosporum* sp., *Shorea leprosula*, *Sterculia macrophylla*, *Whitfordiodendron pubescens*, *Trema orientalis*
Monolepta cavipennis		Chrysomelidae	Indonesia, Hong Kong, India, China, Thailand, Vietnam	*Avicennia alba*
Rhyparida wallacei	Wallace's leaf beetles	Chrysomelidae	Singapore, Malaysia	Many mangrove species including *Rhizophora mucronata*

[6] In light of the absence of detailed exotic pest reports on mangroves, this list includes reports of pests affecting all mangroves regardless of whether they are an Australian mangrove species. This information may help to guide thinking on the types of pests that affect mangroves. Further, pests may affect closely related species that are not documented as hosts.

SCIENTIFIC NAME	COMMON NAME	FAMILY	DISTRIBUTION	MANGROVE AND OTHER HOSTS
Xyleborinus aemulus	Ambrosia beetle	Curculionidae	South Africa	*Acacia* sp., *Acalypha glabrata* (copperleaf), *Fagara capensis*, *Gonionia camassi* (wild hyacinth), *Ocotea bullata* (black stinkwood), *Olea capensis* (black iron wood), *Podocarpus falcatus*, *Quercus* sp., *Rapanea melanophloeos*, *Virgilia capensis* (cape lilac), *Xymalos monospora* (lemonwood)
DECAPODA				
Aratus pisonii	Mangrove tree crab	Grapsidae	USA, Central America, Caribbean, South America	Mangrove species *Avicennia* spp., *Rhizophora* spp., *Laguncularia* spp., and *Pelliciera* spp. and littoral algae
Sesarma reticulatum	Purple marsh crab	Sesarmidae	USA	Saltmarsh (*Spartina alterniflora*) and mangroves
DIPTERA				
Actilasioptera falcaria		Cecidomyiidae	Indonesia, India	*Avicennia officianalis*
Meunieriella avicenniae (previously *Cecidomyia avicenniae)*		Cecidomyiidae	USA, Cuba, Brazil, Central America	*Avicennia germinans*
HEMIPTERA				
Aulacaspis marina		Diaspididae	Indonesia, Malaysia, Philippines	Mangroves; *Avicennia* spp., *Bruguiera* spp. and *Rhizophora* spp.
Petrusa epilepsies	Sea grape flatid	Flatidae	USA, Caribbean	Wide range of ornamental plants. Coffee, mango, *Avicennia germinans* (mangrove)
Telmapsylla minuta		Psylloidea	Costa Rica, USA	Black mangrove (*Avicennia germinans)*
LEPIDOPTERA				
Aucha velans	Tide-watching mangrove moth	Noctuidae	South East Asia	*Avicennia* spp. mangroves

SCIENTIFIC NAME	COMMON NAME	FAMILY	DISTRIBUTION	MANGROVE AND OTHER HOSTS
Aucha villiana		Noctuidae	Singapore	*Avicennia* spp.
Orvasca subnotata	Castor hairy caterpillar	Erebidae	Bangladesh, Hong Kong, India, Pakistan, Sri Lanka, Thailand	*Acacia*, mangrove, tamarind, nerium, chrysanthemum, moringa, cashew, groundnut, mulberry, grapevine, pearl millet, linseed
Hypsipyla grandella	Mahogany shoot borer	Pyralidae	USA, Japan, Mauritius, Caribbean, South America, Central America	Mahogany species, cedro species, mangrove
Junonia evarete	Tropical buckeye	Nymphalidae	Africa, USA, Caribbean, Central and South America	Black mangrove (*Avicennia germinans)*
Megalopyge opercularis	Southern flannel moth	Megalopygidae	USA, Central and South America	Larvae are polyphagous and are recorded from plant species belonging to 41 genera. Hardwoods.
Oiketicus kirbyi	Bagworm	Psychidae	Central and South America, the Caribbean Islands	Feeds on plants of 40 families. Hosts include banana, *Rhizophora* spp. *Avicennia* spp., citrus, avocado, ornamental trees
Orgyia postica	Cocoa tussock moth	Erebidae	Hong Kong, Bangladesh, Brunei Darussalam, China, India, Indonesia, Japan, Laos, Thailand, Vietnam, Papua New Guinea	Polyphagous including Java plum, mango, pear, black mangrove, rose, durian, maize, mulberry
Phocides pygmalion	Mangrove skipper	Hesperiidae	USA, Mexico, Argentina, Belize	Red mangrove (*Rhizophora mangle*)
ORTHOPTERA				
Stilpnochlora marginella		Tettigoniidae	Mexico	*Avicennia schaueriana* (mangrove)

SCIENTIFIC NAME	COMMON NAME	FAMILY	DISTRIBUTION	MANGROVE AND OTHER HOSTS
PATHOGENS				
BOTRYOSPHAERIALES				
Phyllosticta hibiscina		Botryosphaeriaceae	USA	*Avicennia germinans*
CAPNODIALES				
Pseudocercospora mapelanensis		Mycosphaerellaceae	South Africa	*Barringtonia racemosa* (freshwater mangrove)
CHAETOTHYRIALES				
Cyphellophora sp.		Cyphellophoraceae	South Africa	*Avicennia marina*
DIAPORTHALES				
Cytospora rhizophorae		Valsaceae	Puerto Rico, Dominican Republic	*Rhizophora mangle*
XYLARIALES				
Anthostomella rhizophorae (Pterosporidium rhizophorae)		Xylariaceae	Hong Kong, Bermuda, Puerto Rico, Venezuela	*Rhizophora mangle*

Table 2: *Priority marine pests, able to survive in mangrove communities.*

SCIENTIFIC NAME	COMMON NAME	FAMILY	DISTRIBUTION	MANGROVE AND OTHER HOSTS
DECAPODA				
Eriocheir sinensis	Chinese mitten crab	Grapsidae	China, Korea, Taiwan, Canada, USA, Europe, United Kingdom (UK), USA	Survives in mud flats and shallow waters. Feeds on vegetation and small invertebrates such as worms and clams.
Charybdis japonica	Asian paddle crab	Portunidae	China, Japan, Korea, Malaysia, Taiwan, Thailand, USA, New Zealand	Feeds on bivalves, fish and other small invertebrates.
ENTEROGONA				
Didemnum vexillum	Carpet sea squirt	Didemnidae	Japan, USA, New Zealand, Netherlands, France, Ireland, England, North Wales	Hard substrates, e.g. ropes, boat hulls, pilings.
MYTILIDA				
Perna viridis	Asian green mussel	Mytilidae	India, Thailand, Malaysia, Japan, Philippines, China, Hong Kong, USA, Jamaica, Trinidad and Tobago, Venezuela, Fiji	Hard substrates.
VENEROIDA				
Mytilopsis sallei	Black-striped false mussel (Caribbean false mussel)	Dreissenidae	Native to Caribbean and Mexico. Non-native range includes Egypt, Gabon, Senegal, Fiji, Japan, Taiwan, Hong Kong, China, Philippines, Thailand, Singapore, Malaysia	Filter feeder. Grows on a variety of hard and soft substrates.

The lack of detailed literature has resulted in a somewhat brief exotic mangrove threat list. This is unlikely to be indicative of the actual risks, but rather the attention or investment afforded to biological threats and impacts within these communities. Further, it cannot be assumed that all pests listed in Table 1 are exotic. Due to the lack of scientific literature, it is possible that some of these species may be present in Australia.

References to mangrove herbivory or microorganism affects are not scarce, but an absence of further investigation into and details of these pest and their effects is widely acknowledged (Rahaman 2002; Tavares de Menezes and Peixoto 2009; Jenoh et al. 2016). For example, researchers identified 195 insect species inhabiting mangroves in Yingluo Bay, Guangxi province, China (Jiang et al. 2000). Furthermore, Chen et al. (2017) reported frequent defoliation of *Avicennia marina* by an unknown pest in China. Additionally, Tong et al. (2006) recorded 24 herbivorous insect species in the mangrove forests of Hong Kong, and Murphy (1990) recorded 102 herbivorous insect species in the mangrove forests of Singapore. The majority of pest reports were not further described or identified beyond family rank. Farnsworth and Ellison (1999) reported 66 herbivorous pest species affecting the mangrove forests in Belize, resulting in a reduction in leaf area by 4.3-25.3% in *Rhizophora* spp. and 7.7-36.1% in *Avicennia* species. Other studies report large-scale outbreaks of herbivorous insects affecting mangrove forests (Onuf et al. 1977; Robertson and Duke 1987a; Anderson and Lee 1995; Mehlig and de Menzes 2005; Ditzel Faraco et al. 2019). Investigation by Burrows (2003) into the pests of *Avicennia marina* and *Rhizophora stylosa* in north Queensland identified 61 insect species feeding on mangroves, a number comparable to herbivorous pests of tropical forest trees. It is important to note that insects feeding on mangroves are not necessarily pests, however, the results indicate the incidence of insects which do use mangrove as a host.

From these studies, it can be concluded that associated organisms can have a moderate impact on mangrove productivity (Cannicci et al. 2008; Perillo et al. 2018). Additionally, some organisms have a propensity to rapidly change population density over large spatial scales. Cannicci et al. (2008) suggested that reports of mangrove pest incidence are likely to be a considerable underestimation due to a variety of factors including abscission of damaged leaves, feeding type and survey methods such as sweep netting favouring larger or slower invertebrates. Identifying pests of concern for environmental biosecurity within an Australian context is a complex task.

Many of the major pest outbreaks or negative impacts associated with pest or disease presence occurred when the mangrove trees were already stressed. Primary stressors which increased the vulnerability of pest attack included drought, storm damage, salinity changes, pollutants and pneumatophore siltation after extended flooding (Murphy 1990; McKillup and McKillup 1997; Saur et al. 1999; Alongi 2002; Osario et al. 2017). Osorio et al. (2017) reports that a combination of environmental and anthropogenic pressures likely resulted in increased disease susceptibility in South African mangroves. For example, although *Cyphellophora* sp. causes lesions on *A. marina,* it is more likely that the fungus is an opportunistic coloniser of weakened trees and would not be a serious threat under normal conditions (Osorio et al. 2017).

All reports of mangrove pest outbreaks were of pests endemic to the survey region. This highlights the complexity and uncertainty in predicting impact and preparing for specific pest threats of mangrove communities. It also establishes the important interplay between ecological management and biosecurity outcomes which will be discussed in further detail on pages 33-34.

Current preparedness for pests of mangrove communities

No preparedness or awareness activities have been undertaken for any of the exotic plant pests of mangrove, saltmarsh or seagrass species identified in Table 1. However, passive surveillance is an approach used widely in marine biosecurity operations. Passive surveillance is an important tool which has successfully detected a number of marine pest incursions. Passive surveillance does not target specific pests or sites but relies on reporting unusual sightings. Active surveillance is also an important tool that does not need to have specific targets. Non-targeted active surveillance such as that performed by NAQS, boat cleaning contractors and mining companies has also resulted in a number of exotic marine pest detections.

Table 3 provides a summary of the biosecurity activities for the exotic pests identified in Table 2.

Table 3: *Current preparedness activities for priority exotic environmental pests that can survive in mangrove communities.*

PEST COMMON NAME (SCIENTIFIC NAME)	DIAGNOSTICS	SURVEILLANCE PROGRAMS FOR TARGET PESTS[7]	FACTSHEETS/ PUBLIC AWARENESS MATERIAL	PREPAREDNESS DOCUMENTS	EPPRD CATEGORY	LISTED ON DAWE NPPP OR THE PRIORITY LIST[8]
Chinese mitten crab (*Eriocheir sinensis)*	DNA barcoding available	Queensland ports: Marine pests surveillance program at Brisbane, Gladstone, Mackay, Townsville and Cairns. WA State-Wide Array Surveillance Program (SWASP) operates at Broome, Port Hedland, Dampier, Cape Preston, Geraldton, Fremantle, Garden Island, Albany and Esperance ports. NT Fisheries surveillance at Groote Eylandt, Melville Island, Gove Harbour and Darwin.	Marine Pests website, NSW DPI website, NSW ID Guide – national system for the prevention and management of marine pest incursions, Primary Industries and Regions South Australia (PIRSA) website, Biosecurity South Australia (SA) aquatic threats brochure, SA Recreational Fishing Guide App, Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE) identification guide, NT Department of Primary Industries and Regional Development (DPIRD) identification guide, QDAF marine pest and disease guide, Business Queensland webpage, Marine Pest Identification Guide	Generic response plan for marine pests developed[9]	n/a	Yes – the Priority List
Asian paddle crab *(Charybdis japonica)*	DNA barcoding available	WA SWASP - Broome, Port Hedland, Dampier, Cape Preston, Geraldton, Fremantle, Garden Island, Albany and Esperance.	DPIPWE Identification Guide, DPIRD Marine Pest Alert fact sheet, DPIRD Dive Pest ID Guide, NSW DPI Marine Pest Incursion ID Guide, NSW DPI website, Marine Pests website, Marine Pest Identification Guide, Biosecurity SA fact sheet, Biosecurity SA boat ramp signs	Generic response plan for marine pests developed	n/a	Yes - the Priority List
Carpet sea squirt (*Didemnum vexillum*)		WA SWASP at Broome, Port Hedland, Dampier, Cape Preston, Geraldton, Fremantle, Garden Island, Albany and Esperance ports. NT Fisheries surveillance at Groote Eylandt, Melville Island, Gove Harbour, Darwin. Queensland ports: Marine pests surveillance program at Brisbane,	Biosecurity SA brochure for *Didemnum* spp., DPIPWE Identification Guide, NSW DPI exotic marine pests webpage	Generic response plan for marine pests developed	n/a	Yes - the Priority List

[7] Other surveillance activities may be undertaken, but PHA were unable to locate information regarding surveillance activities conducted at other ports.
[8] Two priority pest lists developed by DAWE include the National Priority Plant Pest list (NPPP) and the Priority List of Exotic Environmental Pests and Diseases (the Priority List).
[9] Available at https://www.marinepests.gov.au/sites/default/files/Documents/empplan-rapid-response-manual-generic_0.pdf

PEST COMMON NAME (SCIENTIFIC NAME)	DIAGNOSTICS	SURVEILLANCE PROGRAMS FOR TARGET PESTS[7]	FACTSHEETS/ PUBLIC AWARENESS MATERIAL	PREPAREDNESS DOCUMENTS	EPPRD CATEGORY	LISTED ON DAWE NPPP OR THE PRIORITY LIST[8]
		Gladstone, Mackay, Townsville and Cairns.				
Asian green mussel (*Perna viridis*)	DNA barcoding available	Queensland ports marine pests surveillance program at Brisbane, Gladstone, Mackay, Townsville, Cairns. WA SWASP - Broome, Port Hedland, Dampier, Cape Preston, Geraldton, Fremantle, Garden Island, Albany and Esperance ports. NT Fisheries surveillance at Groote Eylandt, Melville Island, Gove Harbour and Darwin.	PIRSA webpage, Biosecurity SA Aquatic Pest brochure, SA Recreational Fishing Guide App, NT Fisheries webpage, DPIRD Marine Pest fact sheet, DPIRD Dive Pest ID Guide, DPIRD Introduced Marine Species fact sheet, Queensland Marine Pest and Disease Guide, Business Queensland webpage, QDAF fact sheet, NSW ID Guide - National System for the Prevention and Management of Marine Pest Incursions, NSW DPI marine pests poster, Marine Pests webpage, Marine Pest Identification Guide, NT Fisheries Marine Pest Dive Cards and 3D moulds	Rapid response plan developed[10]	n/a	Yes - the Priority List
Black-striped false mussel *(Mytilopsis sallei)*	SARDI - developed qPCR assays	Queensland ports: Marine pests surveillance program at Brisbane, Gladstone, Mackay, Townsville and Cairns. Port of Adelaide 2001, 2007-8 and 20010-11. Port Lincon, Whyalla and Eyre Peninsula ports 2010, Whyalla, Port Lincon, Wallaroo, Port Adelaide, Darwin, Cairns, Sydney, Melbourne, Hobart and Perth 2015-16 WA SWASP at Broome, Port Hedland, Dampier, Cape Preston, Geraldton, Fremantle, Garden Island, Albany and Esperance ports. NT Fisheries surveillance at Groote Eylandt, Melville Island, Gove Harbour, Darwin.	NT Fisheries webpage, DPIRD fact sheet, DPIRD Dive Pest ID Guide, DPIRD Introduced Marine Species fact sheet, Marine Pest and Disease Guide, Business Queensland webpage, NSW ID Guide - National System for the Prevention and Management of Marine Pest Incursions, NSW DPI marine pests poster, Marine Pests webpage, Marine Pest Identification Guide, PIRSA webpage, NT Fisheries Marine Pest Dive Cards and 3D moulds, AUSMEPA Website - Marine Pests and Threats in Australian Waters, Marine Education Society of Australasia: Marine Pests webpage	Rapid response plan developed[11]	n/a	Yes - the Priority List

[10] Available at https://www.marinepests.gov.au/sites/default/files/Documents/empplan-rapid-response-manual-mytilopsis-sallei-perna-viridis_2.pdf
[11] Available at https://www.marinepests.gov.au/sites/default/files/Documents/empplan-rapid-response-manual-mytilopsis-sallei-perna-viridis_2.pdf

Pathway risks

Risk pathway analysis

The entry pathways for exotic pests to mangrove communities were analysed by gathering data (where available) on interceptions, detections, imports, literature reports, and using expert elucidation to assign relative risk to each biosecurity risk entry pathway. There are limitations to the data used in the pathway analysis regarding data gaps and context for interpretation. Thus, participation of DAWE experts with experience of border operations was crucial to the proper interpretation of pathway risk.

It is important to note that though the relative risk of each pest family was ascribed in the pathways analysis, the relative risk of entry is not indicative of their establishment potential or impact. The literature was not comprehensive enough to adequately ascribe impact. Another crucial consideration when examining entry pathways risk is whether the risk of a particular pathway can be managed. If the risk cannot be managed then investment is better targeted elsewhere.

PHA facilitated a workshop with technical experts from the DAWE and QDAF to conduct risk pathways analysis. The workshop elucidated several useful outcomes when thinking about both mangrove community biosecurity and environmental biosecurity planning in a general sense. The workshop concluded that:

- There are a number of genuine pathways for the entry of mangrove pests and pests that can survive in mangrove ecosystems. These are outlined in Table 4.
- The risk pathways of highest concern for pests of mangrove, saltmarsh and seagrass are hitchhiking pests and the illegal import of plant and animal material through the mail.
- The risk pathways of highest concern for marine pests that survive in mangrove ecosystems are through the illegal import of species via mail for the pet and restaurant trade and biofouling.
- There are many unknowns regarding understudied plant taxa like mangroves. This contributes to the difficulty in accurately profiling risk. Risk pathways analysis are difficult even for well-studied crops and pests because of all the systems components, inherent uncertainties and variables.
- The commercial pathways are well managed, but the risk associated with unmanaged pathways is unknown and expected to be increasing. Leakage surveys have been completed for airport passenger baggage and illegal plant imports but significant gaps in knowledge remain and what is known is expected to be an underestimation.

NOTE: PHA adapted the methodology as used by DAWE for Import Risk Assessment and the PHA Biosecurity planning process to undertake this pathway risk analysis and also took into account the "environmental" modifications PHA made to this process while undertaking the Acacia biosecurity risk mitigation process. None of these processes can be used for "definitive" determination of risk in an environmental pathway risk assessment as the pathways for movement are not clear eg hitchhiking pests can move on any product and the establishment potential also less understood. PHA engaged DAWE and QDAFF experts in expert elicitation and the outcomes in this document are bested on the assessment of the limited information available. This project confirms the complexity of undertaking pathway risk assessment for environmental species eg Acacia or environments eg mangroves.

Table 4: *Comparative risk of biosecurity risk pathways for mangrove communities.*

Risk comparison	Order: Family	Most likely pathway/s
Higher risk	Coleoptera: Cerambycidae (Longhorn beetles)	Imported plant material: commercial timber imports, dunnage Passenger baggage: wooden artefacts Mail: wooden artefacts
	Coleoptera: Chrysomelidae (leaf beetles – eg seed beetles, tortoise leaf beetles, leaf monkey beetles)	Hitchhiking: RoRo (Roll-on/roll-off vessels), other vessels Imported plant material: cut flowers
	Coleoptera: Curculionidae (true weevils)	Hitchhiking: RoRos, other vessels Passenger baggage: wooden artefacts Mail: wooden artefacts
	Lepidoptera: Pyralidae Eg pyralid moths, snout moths or grass moths)	Imported plant material: commercial Hitchhiking: Dunnage, containers, other vessels
	Lepidoptera: Noctuidae (eg owl moths, cutworms, armyworms)	Imported plant material: commercial Hitchhiking: dunnage, containers, vessels
	Lepidoptera: Erebidae (eg Tiger moths, Tussock moths)	Imported plant material: commercial Hitchhiking: dunnage, containers, wind pathway Movement of people and goods from Papua New Guinea to the Torres Strait
	Decapoda: Grapsidae, Varunidae (eg Chinese mitten crabs)	Ballast water Hitchhiking (biofouling): sea vessels Passenger baggage: smuggling live crabs Mail Illegal import of live crabs
	Mytilida: Mytilidae (eg green lipped mussels)	Ballast water Biofouling
	Veneroida: Dreissenidae (eg Small freshwater mussels)	Ballast water Biofouling
Intermediate risk	Decapoda: Portunidae (eg swimming crabs, blue swimming crabs)	Ballast water Hitchhiking (biofouling): sea vessels Passenger baggage: smuggling live crabs Mail: Illegal import of live crabs
	Hemiptera: Diaspididae (eg Scale insects)	Imported plant material: illlegal
	Diptera: Cecidomyiidae (eg gall midges)	Hitchhiking: RoRos, other vessels Imported plant material: commercial, illegal
	Enterogona: Didemnidae (eg colonial tunicates)	Ballast water Biofouling
Lower risk	Hemiptera: Psylloidea (eg true bugs, jumping plant lice)	Imported plant material
	Lepidoptera: Hesperiidae (eg butterflies, skipper butterflies)	Hitchhiking: dunnage, containers, vessels
	Lepidoptera: Megalopygidae (eg flannel moths, crinkled	Imported plant material: commercial Hitchhiking: dunnage, containers, vessels

Risk comparison	Order: Family	Most likely pathway/s
	flannel moths)	
	Lepidoptera: Psychidae (eg caterpillars, bagworms, case moths)	Imported plant material: commercial Hitchhiking: dunnage, containers, vessels
	Lepidoptera: Nymphalidae (eg butterflies, brush-footed butterflies)	Imported plant material: commercial Hitchhiking: dunnage, containers, vessels
	Hemiptera: Flatidae (eg fulgoroid planthoppers)	Imported plant material Illegal
	Orthoptera: Tettigoniidae (eg katydids, bush crickets)	Mail: illegal import of plants, illegal pet trade Import of plant material: commercial
	Decapoda: Sesarmidae (eg marsh crab, red-clawed crab)	Ballast water Hitchhiking: sea vessels
	Archaeopulmonata: Ellobiidae (eg hollow – shelled snails)	Hitchhiking: dunnage, car imports Mail: wooden artefacts, illegal pet trade
	Capnodiales: Mycosphaerellaceae (eg sac fungi)	Hitchhiking: clothing and equipment Mail: illegal import of plant material Passenger baggage: smuggling of plant material
	Diaporthales: Valsaceae (eg sac fungi)	Hitchhiking: clothing and equipment Mail: illegal import of plant material Passenger baggage: smuggling of plant material
	Chaetothyriales: Cyphellophoraceae (fungi)	Hitchhiking: clothing and equipment, vector hitchhiking (dunnage, plant material) Mail: illegal import of plant material Passenger baggage: smuggling of plant material
	Xylariales: Xylariaceae (ascomycetous fungi)	Hitchhiking: clothing and equipment Mail: illegal import of plant material Passenger baggage: smuggling of plant material
	Botryosphaeriales: Botryosphaeriaceae	Hitchhiking: clothing and equipment Mail: illegal import of plant material Passenger baggage: smuggling of plant material

General risks to biosecurity identified by discussions with stakeholders

The following general biosecurity risks to mangrove communities have been identified through stakeholder consultation and learnings from this project. A number of interdependent social dimensions are the key to improved biosecurity in mangrove communities where threats are poorly understood, human population density is low, habitats are remote and difficult to traverse and the impacts on stakeholders may not be immediately obvious.

Many of the general biosecurity risks to mangrove communities are common to environmental species across the board and are shared with or related to the general biosecurity risks identified in the *Environmental Risk Mitigation Plan for Australian Acacia Species*. Addressing many of these gaps will improve environmental biosecurity outcomes across a range of taxa.

Threat list is incomplete

Uncertainty characterises the biosecurity threat status of mangrove communities because the threat list is incomplete. Published literature that addresses exotic mangrove, saltmarsh and seagrass pests is limited. The few exotic pests that were identified have minimal supporting information on their biology or ecology. Pests that have been described are often addressed in one or two papers on one specific host. Since these pests have not been well studied it is possible that these pests have much broader hosts lists that are not documented. Additionally, it is common for species to become pests only once introduced into a new environment where conditions and lack of natural enemies are conducive to their establishment and proliferation. This paucity of basic pest and host information limits the reliability of the risk analysis.

Information is also inadequate to ascertain the overall impact of the pests and diseases on the list. The pest identification and subsequent risk pathway analysis was completed as comprehensively as possible for the information available, however, it is likely that the literature (and the resulting list) underestimates the pests and diseases affecting these communities. Studies in Australia have previously documented 61 herbivorous insects on *Avicennia marina* and *Rhizophora stylosa* mangroves in Queensland (Burrows 2003). Based on this, it may be reasonable to assume that mangroves in other countries support similar faunal assemblages. The precautionary principle should be applied to expect that there are additional pests to mangrove communities overseas which have not been documented. It is also possible that some of the 'exotic' pests and diseases of mangrove communities may be present in Australia.

Though a literature review identified 31 exotic pests and diseases that could affect mangrove communities, none of these are listed on global invasive pest databases. Additionally, most reports did not convey evident concern for the pests and generally noted them as being a minor nuisance or as occasional flare-ups. Although the impact that exotic pest or disease species may have under Australian conditions cannot be known, the lack of concern in the published and grey literature may suggest that with current knowledge and risk assessment tools there are no standout pest threats of high priority. Although it is not comprehensive for all potential threats, completing the literature review confirms that there are no significant or obvious recorded threats missing from planning discussions and activities. Knowing this helps direct the focus for preparedness activities. Periodic reviews of the literature and development of contacts to tap into unpublished information would be useful towards effective notification of emergent pests of mangrove communities.

This inability to develop a comprehensive threat list suggests that the greatest risks to mangrove communities may be the unknown unknowns. That is, pests that have not been well documented or that cause minimal impact within their native range but could become significant pests in a new environment.

This, together with the difficulty in resourcing activities across the wide expanse of coastline supports a general preparedness approach focused toward target locations that have a higher risk of pest entry. Preparedness activities could be aligned with the risk profile at each location. For example, the risk of pest entry via the international airport and cruise liners is higher in Cairns than in Newcastle. In Newcastle the primary mangrove pest pathway risk is the port.

Increases in cruise shipping and itinerant vessel visits

Opportunities for the introduction of plant pests have increased alongside increases in global trade and travel (Hulme 2009; Sikes et al. 2018). The cruise shipping industry in Australia and surrounding regions has grown by almost 10% each year since the early 2000s (Douglas et al. 2018). More cruise ships are making more trips to a wider variety of destinations and more Australian ports are opening themselves up to cruise tourism. In 2018-19, 50 cruise ships visited Australia, making an average of 26 port visits per trip (Douglas et al. 2018). There has been an increasing trend to decorate passenger cruise ships with live plants including flower and fruit trees, green walls and real turf putting greens. In addition to the increased risk posed by the greater movement of people on cruise ships, this plant material poses a substantial risk to Australian biosecurity because it provides the conditions to facilitate the survival of a broader range of pests and diseases in transit. This adds to the risk of the hitchhiking pathway which was identified to be a primary pathway for a number of mangrove community threats (Table 4). The risk of hitchhiking pests to mangrove communities is particularly pertinent due to the proximity of mangrove communities to most major Australian entry points (sea and air) (Appendix 2: Tables 8-11). Plant material on cruise ships is required to be covered while ships are docked, though this does not adequately mitigate the risk of pests being transported with the offloading of passengers on shoes, clothing, and wind. Live plant material on cruise ships has been identified as a real risk to biosecurity that needs to be managed.

Cruise ship biofouling is also an established vector of marine pests. Many cruise ships operate in South Pacific and Asian ports where marine pests are present and populations of marine pests may establish in vessel niches. A number of marine pests have been detected on vessels in this way. While the short turnaround time of many cruise ships may reduce the risk, the risk is still present with increasing numbers of visits.

Cruise ship staff have good awareness of biosecurity as it relates to their operations. Cruise ship kitchens and catering are well controlled, and the staff are appropriately trained in biosecurity adherence. The primary risk lies with the passengers and the increasing numbers of them. As an example, passengers may bring plant material from one country into their rooms and throw it overboard when it is dies while at port in another country. Alternatively, cruise ship passengers may visit a mangrove site overseas and collect fungal spores on their clothing and then wear this same clothing kayaking in mangroves in Australia, potentially spreading disease.

The steady increase in superyacht numbers is also a biosecurity risk across a range of environmental and agricultural taxa. Superyacht owners are not as motivated to prevent biosecurity incursions in the same way that businesses who facilitate travel or trade are. Superyachts also have a tendency to call in at smaller uninhabited islands, or secluded coastal locations once they have cleared first ports of call (and on occasion, before clearing first port of call). Biosecurity risks are thus potentially carried into mangrove/seagrass ecosystems at sites remote from settled areas where early detection is even less likely. Additionally, these vessels often sit in ports for extended periods of time while awaiting direction from the owner.

This increases the risk of biofouling. To compound this there is a high turnover of staff on these vessels and the owners may fly onto and off their superyachts directly from overseas. Like cruise ships, superyachts can have live decorative plants and wooden materials on board and many bring pets and exotic foods with them. Some vessels have been found harbouring live termites and ants. Superyachts are met on arrival by quarantine staff and foodstuffs are incinerated by accredited contractors. However, the increasing number of superyacht arrivals poses an increased risk.

Primary stressors increasing the vulnerability of mangrove communities

Mangrove forests are recognised as one of the most endangered ecosystems worldwide. Despite the well documented importance of mangrove communities to ecological function, industries and the community, 20 to 35% of global mangrove area has been lost since 1980 (Polidoro et al. 2010). As discussed on pages 7-8, there are a wide range of stressors which threaten mangrove communities and impinge on their health and survival.

Of particular concern to biosecurity considerations is the interplay of stressors which reduce the resilience of individual mangrove trees. Stressors such as drought, periods of extreme temperature, pollution, flooding, salinity changes, cyclones and other storm events weaken mangrove communities and increase their vulnerability to secondary pest or disease attack (Daly 2013; Lymburner et al. 2019). The literature repeatedly documented serious pest outbreaks when mangroves were already stressed (Murphy 1990; McKillup and McKillup 1997; Saur et al. 1999; Alongi 2002; Osario et al. 2017).

Many of these stressors are predicted to increase in frequency and/or severity under the effects of climate change. Further, the effects of climate change on pest behaviours, lifecycle and host range may also work to increase threats to mangroves. Stressed mangroves around points of pest entry could facilitate the establishment of a pest that may have otherwise not found a suitable host. Alternatively, the favourable conditions created by weakened mangrove forests could facilitate accumulation of pest populations in ways that could drive permanent equilibrium change in the environment (Crous et al. 2016).

Degraded marine environments are often predisposed to invasion by opportunistic marine species including marine pests. As many mangrove, seagrass and saltmarsh communities near points of entry are affected by human activities, the likelihood of entry and establishment of pest species is heightened.

This highlights the important overlap between environmental management and biosecurity. The 2015-16 dieback of 1000 km of mangroves along the Gulf of Carpentaria coastline is presumed to be the result of a temporary drop in sea level coinciding with prolonged drought conditions and extreme January temperatures (Duke et al. 2017). Since the initial dieback, the mangroves have encountered subsequent difficulties. The trunks of the dead mangroves are being repeatedly smashed by the waves into re-growing plants and some mangroves in the area have experienced subsequent caterpillar infestations. Analogous to the agricultural space where growers are encouraged to make biosecurity part of their daily routine, environmental health and biosecurity threats should not be approached in isolation of each other. Developing and integrating systems-based strategies will serve to mitigate simultaneous and potentially compounding risks to the environment. However, it must be recognised that coastal environments are highly dynamic and changes in shorelines, sedimentation and coastal plant communities are natural events, and may not be amenable to management to return to a previous state.

Numerous studies into the effective engagement of the community with biosecurity messages have stressed the importance of avoiding duplication of effort and creating additional groups that require separate involvement (Kruger et al. 2010; Carrier et al. 2012). People are busy and have a multitude of competing causes vying for their attention. All the discussions that PHA project staff had with stakeholders across the three case study locations elicited at least some concern for mangrove community health and protection.

However, biosecurity was never a main concern or at the top of mind. The immediate nature of threats such as clearing, pollution and water quality reductions escalates the priority of these pressures in people's minds.

Given this, and the lack of stand-out pest threats, it is inefficient to try to make biosecurity a primary focus of local stakeholder groups when they perceive more tangible threats. Many environmental and scientific groups are already mobilised, working to protect mangrove communities from these existing threats and are already collecting data which may be jointly useful for biosecurity outcomes. Engagement of the environmentally conscious segment of the community could be best achieved by supporting and expanding the existing framework to achieve collective goals.

As an example, there are a number of groups and initiatives such as ReefBlitz, MangroveWatch, Seagrass Watch, and the Cairns and Far North Environment Centre (CAFNEC) in Cairns which all operate in mangrove ecosystems and have an established place within the local community. Biosecurity agencies should build relationships with these key influential organisations to establish a platform to reciprocally share knowledge and feedback. MangroveWatch in particular is an example of a network that is well placed to take on activities related to biosecurity. MangroveWatch has already established and trained local groups throughout the country in aquatic weed identification, reporting and digitally recording mangrove status. MangroveWatch is coordinated through TropWATER in JCU and has established links to key mangrove and coastal health researchers.

Complex jurisdictional structure

Being a fisheries resource, mangrove, saltmarsh and seagrass are under the jurisdiction of state fisheries. Unless on Commonwealth land, fisheries and aquatic biosecurity is conducted by state governments. Due to Australia being a federation, different state and federal legislations apply to mangroves at the high and low tide mark and within national or state protected marine parks which affects jurisdictional access to sites. These multi-jurisdictional responsibilities may delay response measures, e.g. within National Parks and UNESCO World Heritage sites. State fisheries agencies' main engagement with mangrove plants is in the licencing of mangrove removal permits from places where they are impeding amenity, businesses or homes. State and Territory based aquatic biosecurity teams monitor for freshwater and marine pests and operate community awareness campaigns. Freshwater monitoring involves monitoring for non-native fish in waterways, creeks, lakes and drains. Marine monitoring programs focus on marine pests such as mussels and crabs that may travel in ballast water or on vessel hulls as biofouling. Settlement plates and crab hotels are used to monitor for these pests. State based aquatic biosecurity teams and NAQS work with certain ranger groups to raise awareness of specific threats, how to monitor for them and how to send samples. This facilitates some aquatic biosecurity coverage in remote locations across Australia's northern coastline. Commonwealth biosecurity staff have a vessel inspection program which involves a vessel risk assessment prior to entry into the marina. High-risk vessels are inspected and treated as necessary.

Mangrove communities are managed by fisheries teams under state or territory departments. Fisheries perform monitoring within mangrove community environments but only in relation to invasive aquatic animals and weeds. Fisheries teams are not trained in plant health and this may create a blind spot because there is no one who specifically looks for pests or diseases on mangrove plants until the impact becomes serious.

Though mangrove communities are managed by state and territory fisheries teams, the expertise for response to a plant pest incursion within mangrove communities would fall under the relevant plant biosecurity team. These plant biosecurity teams are unlikely to have any existing relationships with the mangrove community stakeholders and so an effective response would require collaboration with the fisheries teams. Processes for working in partnership between teams are not formalised within some state

agriculture/fisheries agencies. Response processes under these conditions may not be tested.

Further, while the state agriculture agencies are better placed to carry out environmental biosecurity response activities, the state environment agencies hold the land management responsibility for large tracts of the national mangrove estate, especially across northern Australia. A response within a mangrove ecosystem may therefore require the combined expertise and coordination of plant biosecurity, fisheries and state environmental agency teams.

Project discussions illuminated some level of uncertainty among state agency staff regarding biosecurity responsibilities in the environmental setting. Given the distribution of expertise and responsibilities, it is important to make the formalisation of arrangements between state and federal departments more well known. This is especially the case as the trend towards larger, decentralised departments can make close working relationships between divisions and departments more difficult. Formalised mechanisms of communication between divisions and departments is also important for the effective flagging of potential issues or opportunities for collaboration.

Limited infiltration of biosecurity messages among stakeholder base

Improving scientific knowledge alone will not improve biosecurity outcomes if the social dimensions of biosecurity are not also attended to (Reed and Curzon 2016). Arguably, the unengaged or disengaged parts of the community are a bigger risk to post-border biosecurity than gaps in other areas. Investment therefore, may be best targeted towards leveraging the social aspects of biosecurity. This is especially relevant in light of the difficulty in predicting and preparing for the range of pests or diseases that could potentially affect mangrove communities (or the broader environment).

Stakeholder awareness of biosecurity issues was variable among case study locations and except for the indigenous ranger groups, awareness was generally low. The indigenous ranger groups engaged in this project and their communities had good awareness of biosecurity responsibilities and know what to do if an unusual pest or pest damage is spotted. The ranger groups are connected to a wide range of research and government groups and are well placed to share and obtain important information.

Stakeholders in Cairns had a greater awareness in regard to what biosecurity is and why it is important compared to stakeholders in Newcastle. A number of recent pest incursions in and around the Cairns region (e.g. yellow crazy ants and Asian honey bee) has elevated biosecurity awareness. Despite this in both locations there remained a reasonably low awareness of what to do if something unusual was spotted. If an unusual pest or pest damage was spotted, most community and environment groups in Cairns reported that they would reach out to other people or groups that they are connected with to seek advice on identification or what to do. Community and environmental groups expressed frustration as they often receive reports from the public regarding environmental pest concerns but that they are not aware of who to pass the information on to.

Except for at the port, stakeholders in Newcastle had low awareness of exotic pest biosecurity. Understanding of biosecurity mainly pertained to established invasive weeds. The Port of Newcastle has good staff awareness and biosecurity processes in place. The DAWE and DPI have a strong presence at the port and the stevedores are aware of high-risk pests and pest reporting, however, the focus here is on vectors of human health and marine pests.

Recreational fishing groups in Newcastle reported that they receive awareness pamphlets of exotic threats from Fisheries but that they ‘don’t know what to do with them.’ Environment groups in Newcastle had some communication with Local Land Services but felt out of touch from the activities of state government. If a pest of concern was observed, the general consensus was that stakeholder groups might contact the

university for help. Stakeholders in engaged Newcastle were not aware of the exotic plant pest hotline.

A 2017 survey of 1,000 Australians involved in marine or estuarine activity either recreationally or professionally found that 51% of survey participants had no awareness of any marine biosecurity activities (Mercer et al. 2017). Furthermore, only 15% were aware of any specific information or campaign relating to marine biosecurity (Mercer et al. 2017). The results from this study broadly align with stakeholder discussions in this project.

In addition, Mercer et al. (2017) indicated that 57% of respondents felt they did not know what to do if they saw something unusual in the water. This was the primary barrier to reporting, along with not wanting to waste staff time, appear foolish if it were not a pest and simply not thinking to report (Mercer et al. 2017). Mercer et al. (2017) also found that if people found something unusual in the water, 29% would take a photo and show it to a connection to discuss what to do and 14% would try to identify it from internet searches. These findings draw attention to the importance of messaging and having key local groups linked in with biosecurity teams.

Overall, stakeholders interviewed by this project expressed that they might get some trickle-down information regarding threats or responses, but that this was often not shared in a timely manner and communication rarely comes directly from state agencies. This project found that although there is limited awareness of biosecurity issues among many of the stakeholder groups, there is an eagerness to be involved in communication chains and activities. Groups wanted to be aware of any serious exotic pest threats to their area so that they could do something about them but they did not know where they might find resources to assist them with that. A number of groups interviewed felt that they were overlooked by government and requested more transparency and involvement in biosecurity planning in their areas. This aligns with the recommendations of previous studies which assert that increased involvement of community stakeholders in biosecurity planning processes is required (Enticott and Wilkinson 2013; Reed and Curzon 2016; Inspector General of Biosecurity 2019).

Due to the vast and often remote distribution of mangrove communities in Australia, the lack of connection with and/or awareness of key groups that frequent those ecosystems is a critical gap. The risk is that if no one perceives the pest or disease threat as their responsibility to report, then problems are likely to remain unknown to authorities. Engaging with the local communities on the ground will serve to give a sense of ownership to stakeholders over biosecurity protection and give them 'permission' to act on their concerns.

Some work has been undertaken towards this in the marine pest space with the development of passive surveillance for marine pests program as part of the Marine Pest Plan. However, further infiltration of biosecurity messaging and risk pathways information may help to reduce behaviour that creates risk to mangrove communities. For example, stakeholders engaged in the aquarium trade may be further engaged to improve their understanding of biosecurity and increase their ownership of shared responsibility towards protecting the environment from exotic aquatic pests, diseases and invasive plants.

Knowledge and resources held in community groups is not adequately utilised

Local and regional stakeholder groups hold a wealth of knowledge that is not available through other sources but would be valuable in biosecurity planning and response considerations. Understanding the community, its practices, the level of understanding and key values would contribute to more complete biosecurity pathways analysis and identification of potential risks before they eventuate.

Individuals within these groups are often practicing or retired specialists with a wealth of experience and skills. This includes leveraging and coordination of community volunteer efforts, conservation, biological

sciences, local traditional knowledge as well as media and communication. Some local environmental groups and individuals are familiar with the intricacies of species diversity and distribution within a local area and they know what is normal and what is not in those landscapes. Additionally, they have knowledge of the expertise available in local networks. As an example, the Hunter Wetlands Centre has been operating for 35 years and holds extensive local knowledge among its 700 volunteers and board of retired researchers and estuarine conservationists.

Stakeholders such as local fishers hold a wealth of knowledge (anecdotal and recorded) that may be crucial during a biosecurity incursion in an environmental setting. Groups such as these are intensely interested in their natural environment but do not see themselves as 'sciencey types', and therefore may not see themselves as being part of the biosecurity or pest management conversation. Stakeholders interviewed in this project expressed the sentiment that their contributions would not be taken seriously or they do not take their own contributions seriously. This may in turn contribute to a disconnect between such stakeholders and biosecurity agencies.

Studies have shown that a failure to recognise and engage with 'non-scientific' biosecurity knowledge of local players can be a limitation in formalised systems (Mills et al. 2011; Enticott and Wilkinson 2013; Simone Crowe pers. comm., 2019). Such studies demonstrate that the combination of local geography and biodiversity knowledge together with more generalised biosecurity knowledge is crucial in more effective decision-making (Enticott and Wilkinson 2013). Including and valuing all players in the conversation is likely to lead to a more 'responsive' biosecurity system (Richards and Higgins 2016). These principles should be kept in mind as discussions and arrangements for improved environmental biosecurity processes continue.

Need for more targeted communication with key stakeholders

Passive awareness campaigns with generalised information on websites or printed material are not effective at engaging stakeholders in changing behaviour (Curnock et al. 2017; Kruger et al. 2010; OceanWatch Australia Ltd 2019). Targeted communication that is tailored to the interests and abilities of specific user groups, such as that being communicated as part of the Marine Pest Plan, is required to achieve improved engagement with biosecurity issues. Additionally, information transfer is most effective when the information is localised. Research by Mercer et al. (2017) found that to be successful, awareness campaigns need to be funded, recognise and target groups of specific attitudes and behaviours separately, be delivered in partnership with locally trusted organisations, use local events to spread messaging and have a clear call to action. Given the different knowledge base, motivation and risk-perception that each stakeholder uses to relate to mangrove communities, different messages and delivery methods will be more or less effective depending on the group.

DAWE's recent environmental biosecurity roundtables have affirmed that people are the key to improved environmental biosecurity outcomes. Projects are sustainable when researchers, government and community come together to design activities and when they involve meaningful community participation. Local community organisations emphasised that the effectiveness of community and volunteer engagement is underpinned by the need to feel valued to remain motivated. Targeting communication and providing feedback on how their activities are contributing is a key way to achieve this. Any model which aims to achieve meaningful engagement with the community or community groups must consider these requirements.

Stakeholders raised that they do not know who to talk to and that no one has ever spoken to them about these issues. Having never being 'spoken to' made stakeholders feel like biosecurity is not their responsibility. Stakeholders reported that existing reporting systems such as the exotic pest hotline are not consistent, calls are not answered and their reports are not followed up on. To maintain community interest in biosecurity

activities, communities must feel that their contributions are valued. This includes responding to every report.

Stakeholders also expressed that face-to-face engagements would be critical to the success of new activity generation. Holding meetings with communities on biosecurity issues will demonstrate that they are an essential part of the shared responsibility approach and have a valuable contribution to make in the protection of their local environment. Further, face-to-face forums would be helpful towards establishing the personal relationships required for building trust and encouraging the two-way dialogue (Shuang and Cook 2016; Kruger et al. 2009; Curnock et al. 2017). A number of stakeholders suggested that getting on the agenda at community information nights or existing community events, such as regattas, community festivals and competitions would be an effective way to engage the community in biosecurity messaging.

Curnock et al. (2017) also found that community gardeners were more inclined to share information about a concerning pest problem with governments and networks if they felt their information would be useful and adequately acknowledged. The paper suggested biosecurity awards, extension officers and articles publicising the community's success as potential avenues to achieve this acknowledgement. This two-way dialogue is necessary for community stakeholders to feel involved and have ownership over biosecurity issues which would otherwise be seen as the biosecurity staff's remit. Additionally, Kruger et al. (2010) found that for engagement to be effective it requires genuineness, responsiveness, trust, credibility, respect, reciprocity, and flexibility. These engagement characteristics would be difficult to achieve without at least initial face-to-face engagements to establish the relationship.

To fulfill these requirements for effective engagement, engagement needs to be local and/or according to themed stakeholder groups. This supports the case for targeting preparedness activities, such as community awareness campaigns to high-risk locations.

Stakeholder groups are highly interconnected and have significant influence on each other

Community and environmental groups are highly interconnected through local and regionalised networks. These groups share information, resources and volunteers regularly and effectively. Environment and community groups are also often involved in advocacy and often have close working relationships with higher levels of local and national government, including members of parliament. For instance, CAFNEC have a standing meeting with the QLD environment minister every three months. To provide another example, there are 280 fishing clubs in NSW which cover 2 million anglers. These fishing clubs share events and information and often share board leadership.

Many of the groups interviewed emphasised the importance of local relationships in creating a sense of community motivation and information flow. This aligns with findings by Curnock et al. (2017) which found that 'the 'softer', less formal institutional characteristics, including individual network connections appear to play a much greater role in influencing stakeholders' engagement, than more formal institutional structures.' Champions for biosecurity messages are utilised within agricultural industries and the concepts are just as relevant in the community and environmental context. Local initiatives sustain continued public motivation when there is a respected group or individual championing the initiative. A study by Oceanwatch Australia (2019) found that when respected organisations participated in biosecurity activities it became a 'social imperative to abide by measures.' These channels of influence are important to recognise for the impact that these smaller local groups can have on national and regional discussions. To leverage these influences, biosecurity agencies should prioritise partnerships with key local groups to enhance delivery of biosecurity messaging.

As well as encouraging adherence to risk prevention measures, vocal local groups also can influence the outcome of incursions through generation of public outcry. A number of historical examples demonstrate the importance of community support and the risk posed by having an unengaged/disengaged community. For instance, in 2012 the response to an incursion of Asian longhorn beetle (*Anoplophora glabripennis*) in England necessitated the removal of all trees within 100 m of a beetle detection. Response operations in urban areas received significant backlash with community protests and inspectors being prevented from entering yards. In order to continue operations, the UK government undertook extensive public engagement including public forums and door knocking to curb the disruption. Extensive resources needed to be diverted to addressing community perception and cooperation during the response which hampered activity (Dr Matthew Everatt pers. comm., 2019). The UK government now regularly engages and pre-emptively trains community groups to facilitate support of biosecurity activities.

PHA recommends that the Australian government expand pre-emptive engagement with key stakeholders to address the gap in stakeholder and community awareness of biosecurity and its consequences. As discussed above, these discussions will be more effective if they occur at the local level so that relationships and trust can be built between biosecurity agencies and local communities. These forums may serve multiple end goals by ensuring that reports of unusual pest activity reach the right people as well as increasing social license for biosecurity agencies to implement response measures during an incursion or ongoing management situation.

In recognition of resourcing constraints and practicality, PHA proposes that high-risk sites for biosecurity incursions be profiled and identified and that biosecurity staff focus on building relationships with stakeholders in locations that are more likely to experience an exotic biosecurity incursion.

Surveillance difficulties

There are no known active plant surveillance activities currently undertaken in mangrove communities. Without a knowledge of what is going on the ground in mangrove communities, the ability to implement activities that seek to protect them is constrained. However, surveillance in mangrove ecosystems is a challenge because ecosystems are remote, crocodiles may be present and survey teams are expensive. Below is a summary of project discussions regarding surveillance for mangrove biosecurity threats.

Several research groups undertake LANsat or aerial mapping of mangrove forests from helicopters on a semi-regular, ongoing basis. Numerous participants suggested that this data could be fed through to biosecurity agencies for surveillance through change detection. However, the sensitivity of change detection through aerial mapping is low and thus its usefulness may be limited since any detection is unlikely to occur with enough time to facilitate eradication or containment. Additionally, mangrove communities can be naturally dynamic and 'changes' may be part of natural processes. Alternative approaches could be explored to increase the frequency, precision, and methodology to remotely detect changes to mangrove ecosystems. For example, the remote sensing of chlorophyll content within canopies could be ground-truthed and modelled to assess plant productivity over time and space.

The use of unmanned aerial vehicles (UAVs) for surveillance in forestry plantations is being employed in New Zealand and by land managers in northern Australia (Mccarthy et al. 2019). Research teams in New Zealand are developing UAVs to detect the pheromones of target pests for peri-urban surveillance. Other developments include the use of UAVs for spot spraying and the design of a spray boom which attaches underneath a helicopter to deliver pesticide to large, remote areas (Scion 2018). Such technologies may be worth consideration during response operations. These technologies could reduce the time taken to detect and delimit incursion sites and helicopter spraying may be preferable to sending response teams into mangrove forests.

Additional to the difficulty of access, there is a lack of clear exotic pest surveillance targets for mangrove and saltmarsh populations. In this context, general surveillance can be a useful tool in identifying new pest incursions and can be undertaken by biosecurity staff and members of the community (Anderson et al. 2016). Passive general surveillance is the main tool for detection of new diseases and pests of aquatic animal and marine health. In this context, specialist survey teams may not always be required if reports from the general public and stakeholders are received and appropriately followed up on.

The use of sentinel sites such as the Cairns Botanic Gardens, the Hunter Wetlands Centre, and the Moreton Bay mangrove research sites which have been mapped continuously for the last five years using permanent monitoring plots may also be appropriate to improve surveillance coverage.

There are many groups already active in the relevant environments who could provide good coverage of general surveillance if they were appropriately engaged. For example, MangroveWatch teams conduct aerial and Shoreview surveys but also commonly receive reports of pest problems from local groups themselves. Indigenous ranger groups are involved in a range of activities within mangrove communities and are well placed to receive additional training and support to enhance general surveillance in mangrove communities and other significant ecosystems. Digital platforms such as MyPestGuide and iMapPESTS could be further promoted to provide support for generalised surveillance from the community.

To support effective general surveillance and maintain public interest, the biosecurity system will need to provide coordination and support. The biosecurity system would need to provide evidence of clear risk or reasoning for the surveillance, clear instructions for sample collection, information on sample triaging and provide feedback on diagnostic results. This is a considerable undertaking and difficult to manage. Here a risk-based approach to community education and support is logical. Pest incursions which occur outside of populated centres may be less likely to be detected in a timely manner and this would limit the potential for eradication. This is the reason that general surveillance effort and training should be targeted to high-risk areas where there is a greater likelihood of pest entry and detection.

Regarding marine pests that can survive in mangrove communities, the National Monitoring Strategy (2005), as part of the National System for the Prevention and Management for Marine Pest Incursions recommended regular monitoring at 18 Australian ports based on an assessment of risk. As of 2015, only 5 of these ports had conducted monitoring (Arthur et al. 2015a). Surveillance activities undertaken through partnerships between state governments, ports and Indigenous ranger groups have increased in recent years though significant gaps remain. The Port of Newcastle is an example of a port deemed to be a higher risk for the introduction of exotic aquatic pests but for which no monitoring exists. Without the use of appropriate surveillance tools there is no way to be certain whether these ports are free of exotic pests or not. Ports such as the Port of Newcastle and others across NSW have discussed establishing their own monitoring collaborations with universities. Collaboration or support from government may advance the activity of such initiatives and provide a mechanism to improve biosecurity monitoring through a shared responsibility approach.

However, points made by Arthur et al. (2015b) must be considered before expansion of resource intensive aquatic pest monitoring activities. Given that only a few aquatic biosecurity pests have ever been eradicated globally, there may be limited benefit of intensive and expensive surveillance. The current Marine Pest Plan has therefore opted for an intensification and targeting of passive surveillance user groups for early detection (activity 2.2, 2.3 and 2.6) (Department of Agriculture and Water Resources 2018). This approach aligns with PHA's recommended approach to support the detection of mangrove plant pests and pests that can survive in mangrove communities.

Some suspicion from industry towards biosecurity agencies

The regulatory relationship between industry and government appears to foster a degree of distrust among some industry stakeholders towards biosecurity agencies. Some stakeholders appeared unwilling to discuss any potential concerns or gaps in management. Other industry stakeholders were not willing to engage at all. Curnock et al. (2017) also reported that some community gardeners interviewed were suspicious of government attempts at engagement, feeling that it might 'impinge' on their activities.

This perceived division between industry and government is a risk to biosecurity. Building trust with industry may improve cooperation and reporting which collectively benefits the sustainability of industry and the environment. Improved cooperation between biosecurity agencies and industry could be achieved through pre-emptive engagement and strengthening of relationships at a local level

RISK MITIGATION PLAN FOR MANGROVES AND ASSOCIATED COMMUNITIES

A plan for implementing improved biosecurity

The process of risk identification and stakeholder consultation has informed the following recommendations in this environmental risk mitigation plan. These recommendations are principally designed for decision-makers to address the gaps in biosecurity for mangrove communities and guide improvements with appropriate consideration of the stakeholder context. Prioritisation of these recommendations considers practicality and priority. Implementing some of the actions will not only strengthen the biosecurity of mangrove communities but also the broader plant biosecurity system.

Table 5: *Implementation table detailing priorities and recommended actions for improved biosecurity of Australian mangrove communities.*

This table summarises the recommendations of this project which have been grouped into broad themes, Engagement, Jurisdictional Structures, Preparedness and Risk Mitigation. Under each broad theme the individual recommendations are aligned to the sections of the report in which their justifications are discussed. The recommendations are prioritised from 1 – 3 and represent the PHA view of priority with 1 being the highest priority and 3 being the lowest priority. The engagement and preparedness priorities were tested and validated at a stakeholder workshop in Cairns on the 18th of February 2021.

PRIORITY	RECOMMENDATION	NOTES
		PREPAREDNESS
Threat list is incomplete		
1	EBO and mangrove stakeholders to undertake general preparedness activities with a focus on locations that are at a greater risk of a biosecurity pest incursion.	The exotic threat list of pests and diseases that affect mangrove communities did not identify any pests or diseases that are standout candidates for specific preparedness or surveillance activities. Thus, improved biosecurity for mangrove communities is best achieved through general preparedness. Completion of a generic risk pathways analysis would be helpful to determine locations with characteristics or activities which may facilitate a greater likelihood of pest entry. Without the ability to cover all coastal areas effectively due to resourcing constraints, targeting general preparedness activities such as community awareness campaigns, general surveillance and response simulations to locations which have a higher risk of incursion may have the biggest impact on risk reduction.
Multifaceted jurisdictional structures		
2	Consider developing generic response plans for exotic plant pest incursions affecting environmentally important species.	The development of generic response plans would help to facilitate thinking within and between state agencies, the Commonwealth and stakeholder groups about the gaps in their processes for environmental biosecurity and their requirements for collaboration and information exchange. The development of generic response plans would assist in rapid decision-making in the event of an emergency plant pest incursion affecting the environment and would increase the effectiveness of response through prior identification of management options. Generic response plans should identify available control methods, resources and equipment required, and provide a list of key groups and technical experts which may be useful to consult in response planning discussions. Generic response plans could also address strategies for leveraging the media to the benefit of response operations and to avoid potential disruption through public outcry. The Emergency Marine Pest Plan and associated rapid response plans are an example of this.

PRIORITY	RECOMMENDATION	NOTES
		ENGAGEMENT
Limited infiltration of biosecurity messages among stakeholder base		
1	EBO to increase public awareness activities and engagement with local groups to highlight environmental biosecurity threats and encourage ownership of biosecurity responsibility.	Increasing understanding of biosecurity risk and encouraging ownership of biosecurity responsibility among the general public and key stakeholder groups will increase the effectiveness of biosecurity operations in environmental settings. Increasing public awareness will help to increase reporting and reduce behaviours in the community that heighten biosecurity risk. Institutional structures and capacity must be in place to support an increased engagement with the 'shared responsibility' approach to biosecurity. Feedback and continued guidance to community members about their activities and contributions is important to maintain activity. To achieve this, personal relationships between community and environment groups and local biosecurity staff who perceive community engagement as part of their remit should be established. In order to support increased community engagement, reporting systems also need to be robust and regularly tested and all reports must be followed up on. Local communities and groups have expressed a desire to be informed and involved in biosecurity considerations that threaten their local area and would appreciate increased understanding of environmental biosecurity threats, consequences, and management options. Understanding of these considerations by the public will increase the social license of biosecurity agencies.
Need for more targeted communication with key stakeholders		
2	EBO and state and territory agencies to ensure that the approach to raising awareness of and engaging groups in environmental biosecurity is targeted to their specific contexts and interests.	The expansive and remote nature of many Australian mangrove communities increases the need for local community engagement with biosecurity messages. However, environmental and community stakeholder requirements for engagement and awareness are not uniform. For awareness activities to be effective, messages need to be targeted and be delivered in a way that is appropriate for the stakeholder. To properly achieve this, some engagement on the local level is required. Increased awareness could be facilitated through community information nights, short-film festivals, videos or through meetings with biosecurity agencies. Initial face-to-face engagements are important to establish the relationship and community ownership. The importance of the face-to-face component was further emphasised by stakeholders during the Mangrove Biosecurity Workshop. Additional tools such as websites and guides can be used to follow-up with messaging after initial face-to-face engagements.

PRIORITY	RECOMMENDATION	NOTES
Stakeholder groups are highly interconnected and have significant influence on each other		
1	EBO and state and territory agencies to prioritise pre-emptive engagement with key influential stakeholder groups to foster a mutual appreciation for stakeholder values and the importance of biosecurity measures and to plan their role in an incursion should one occur in their region.	Coordination of an emergency response requires communication with and support from local stakeholder groups. Goodwill within a community is essential to effectively undertake response activities and key influential stakeholder groups can play an important role in shaping local perceptions on an issue. Historical examples demonstrate that the key to avoiding disruption during an emergency response is early engagement and relationship building to foster an understanding of the importance of response measures and to facilitate cooperation towards a coordinated effort. Although the key influential stakeholder groups engaged in this project are highly connected to each other, they are not currently connected to the biosecurity sections of government. Prioritising engagement with these key groups would likely increase the effectiveness of community messaging and the success of message uptake as groups understand and covey the complexities surrounding biosecurity response decisions. Working with regional organisations would also ensure that any developed material is appropriate. Key local stakeholders could 'champion' the biosecurity message which could increase social licence. PHA proposes that this could best be initiated through workshops with key local stakeholders which simulate an emergency plant pest incursion affecting the environment. Simulations could effectively draw out how stakeholders feel about various environmental values and measures and how they would like to be communicated with and would assist in providing an appreciation for the necessity of biosecurity measures. Any concerns that arise could be discussed and worked out at that time with biosecurity staff.
Surveillance difficulties, Knowledge and resources held in community groups is not adequately utilised		
2	EBO to partner with groups which undertake existing activities within mangrove communities towards increased general surveillance in these ecosystems.	A collaborative approach is key to extending biosecurity reach across Australia's expansive natural landscapes. There are many skilled groups undertaking existing activities in relevant environments that have established links with local communities. Local environmental groups and research teams work towards the protection of coastal wetlands and associated ecosystems through advocacy, education and restoration. These groups are already well established to work with and mobilise local communities against a range of environmental threats. These groups hold in-depth knowledge about baseline conditions, practices, networks and recurring problems in their regions. The experience of these groups would valuably support better environmental biosecurity decision-making and provide greater general

PRIORITY	RECOMMENDATION	NOTES
		surveillance coverage. Consider partnering with groups such as MangroveWatch and SeagrassWatch to support them to extend awareness of exotic biosecurity threats and the importance of reporting unusual pest problems or unusual ecosystem decline symptoms (which may be a consequence of a biosecurity incursion). Collaboration with these groups towards the joint fulfillment of biosecurity and other related environmental outcomes would have resourcing and coverage benefits. This is especially the case considering the interplay between stressed mangrove communities and their increased vulnerability to pest attack.
1	DAWE to continue to support Indigenous ranger groups participation in the biosecurity system.	Traditional owners and Indigenous ranger groups have a good knowledge of what is normal in their environment and notice unusual pest problems quickly. Indigenous ranger groups are well connected to research and government groups and have the skills required to conduct surveillance. The location of many Indigenous ranger groups along remote coastlines where there are few other stakeholder groups means that their increased involvement would valuably contribute to increased coverage of mangrove community biosecurity.
Some suspicion of industry towards biosecurity agencies, Risk pathways		
3	DAWE and state and territory agencies to continue working to build relationships that foster open dialogue with key risk-creators.	During this project, the stakeholders who expressed having a level of distrust of biosecurity agencies were also the ones who reported having no relationship or contact with state/territory or biosecurity agencies. Given the recent improvements in ballast water regulation and biofouling risk assessments, the activity which may have the greatest impact in preventing an incursion of an aquatic pest may be engagement with or deterrence of risk creating groups e.g. itinerant yachts, the illegal import of live seafood, the aquarium trade as well as engaging with the community more generally to prevent the deliberate or accidental release of exotic species.
JURISDICTIONAL STRUCTURES		
Multifaceted jurisdictional structure		
1	Formalise arrangements for communication, collaboration and resource and expertise sharing between state agriculture/fisheries agencies and state environment agencies.	The establishment of the Environmental Biosecurity office (EBO), within DAWE has created a good opportunity to review existing arrangements for environmental biosecurity and to enhance linkages between the various divisions operating within state agencies. It also provides a good opportunity to

PRIORITY	RECOMMENDATION	NOTES
1	Review and promote understanding of the roles of relevant teams and divisions within state agriculture and fisheries and environment agencies for environmental biosecurity.	clarify roles and environmental biosecurity obligations for a unified understanding across and within different agencies.
	RISK MITIGATION	
Risk Pathways		
1	DAWE to continue to support the ongoing development of systems and tools which can assist in the non-destructive detection of hitchhiking pests.	Hitchhiking is a high-risk pathway for pests affecting mangrove communities. Hitchhiking pests are difficult to mitigate against pre-border so adequate resourcing of activities and utilisation of tools at the border is required to reduce the risk of border breaches of hitchhiking pests. Australia must ensure it has good IT systems and resources to record, monitor and review data on observations and detections of risk material at borders, for example frequency and types of host plants on cruise ships and their pests and diseases.

REFERENCES

Anderson C and Lee Y (1995). Defoliation of the mangrove *Avicennia marina* in Hong Kong: cause and consequences. *Biotropica*, 27: 218-226.

Anderson C, Low-Choy S, Whittle P, Taylor S, Gambley C, Smith L, Gillespie P, Locker H, Davis R and Dominiak B (2017) Australian plant biosecurity surveillance systems. *Crop Protection,* 100(2017): 8-20.

Arthur T, Arrowsmith L, Parsons S and Summerson R (2015a). Monitoring for marine pests: a review of the design and use of Australia's national monitoring strategy and identification of possible improvements.

ABARES report to client prepared for the Biosecurity Animal Division of the Department of Agriculture, Canberra, June, CC BY 3.0.

Arthur T, Summerson R and Mazur K (2015b). A comparison of the costs and effectiveness of prevention, eradication, containment and asset protection of invasive marine pest incursions. ABARES report to client prepared for the Biosecurity Animal Division of the Department of Agriculture, Canberra, June, CC BY 3.0.

Australian Institute of Marine Science (2019). Seagrasses. https://www.aims.gov.au/docs/projectnet/seagrasses.html [accessed December 2019].

Australian Institute of Marine Science (2020). Mangrove is more than just a tree. https://www.aims.gov.au/docs/projectnet/mangroves-more-than.html [accesses May 2020].

Alongi DM (2002). Present state and future of the world's mangrove forests. *Environmental Conservation*, 29(3): 331-349.

Balchin JR, Duncan DG, Key GE and Stevens N (2018). Biosecurity on St Helena Island- a socially inclusive model for protecting small island nations from invasive species. *In* Island Invasives: scaling up to meet the challenge. Proceedings of the International Conference on Island Invasives 2017, IUCN, Gland, Switzerland.

Bandaranayake WM (1998). Traditional and medicinal uses of mangroves. *Mangroves and saltmarshes,* 2: 133-148.

Biosecurity New Zealand (2018) Biosecurity 2025 engagement plan- strategic direction 1. Government of New Zealand. https://www.biosecurity.govt.nz/dmsdocument/29168-engagement-plan-strategic-direction-1 [March 2020].

Bureau of Infrastructure, Transport and Regional Economics (2017). Australian Sea Freight 2014–15. https://www.bitre.gov.au/publications/2017/asf_2014_15 [accessed September 2019].

Burrows DW (2003). The role of insect leaf herbivory on the mangroves *Avicennia marina* and *Rhizophora stylosa*. PhD Thesis, James Cook University, Townsville.

Cannicci S, Burrows D, Fratini S, Smith T, Offenberg J and Dahdouh-Guebas F (2008). Faunal impact on vegetation structure and ecosystem function in mangrove forests: a review. *Aquatic botany*, 89: 186-200.

Carrier E, Yee T, Cross D and Samuel D (2012). Emergency preparedness and community coalitions: opportunities and challenges. Center for Studying Health Systems Change, Research Brief 24, Washington.

Chape S, Harrison J, Spalding M, and Lysenko L (2005). Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. *Philosophical Transactions of the Royal Society of Biological Sciences,* 360(1454): 443–455.

Chen J, Shen Z, Lu W, Liu X, Wu F, Gao G, Liu Y, Wu C, Yan C, Fan H, Zhang Y, Zheng H and Tsai C (2017). Leaf miner-induced morphological, physiological and molecular changes in mangrove plant *Avicennia marina* (Forsk) Vierh. *Tree Physiology*, 37(1): 82-97.

Coles RG, Lee Long WJ, Watson RA and Derbyshire KJ (1993). Distribution of seagrasses and their fish and penaeid prawn communities, in Cairns Harbor, a tropical estuary, Northern Queensland Australia. *Australian Journal of Marine and Freshwater Research,* 44(1): 193-210.

Colquhoun E and Ridge Partners (2015). Measuring the economic value of recreational fishing at a national level. Fisheries Research Development Corporation report, Brisbane, January 2015. https://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2012-214-DLD.pdf [accessed May 2020].

Convention on Biological Diversity (2020). Aichi Biodiversity Targets. Convention on Biological Diversity. https://www.cbd.int/sp/targets/ [accessed February 2020].

Creighton C, Gillies CL and McLeod IM (eds) (2015). Australia's saltmarshes: a synopsis to underpin the repair and conservation of Australia's environmental, social and economically important bays and estuaries. *Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication*, James Cook University, Townsville.

Crous CJ, Burgess TI, Le Roux JJ, Richardson DM, Slippers B and Wingfield M (2016). Ecological disequilibrium drives insect pest and pathogen accumulation in non-native trees. *AoB PLANTS*, 9(1): 10.1093/aobpla/plw081.

Curnock M, Farbotko C, Collins K, Robinson CJ and Maclean K (2017). Engaging with risk (or not): shared responsibility for biosecurity surveillance and the role of community gardens. *Geographical Research*, 55(4): 379-394.

Daly T (2013). Coastal saltmarsh. Department of Primary Industries Primefact 1256, First Edition.

Department of Agriculture and Water Resources (2018). Marine Pest Plan 2018–2023: The National Strategic Plan for Marine Pest Biosecurity. *Department of Agriculture and Water Resources*, Canberra, May. CC BY 4.0.

Department of Agriculture, Water and the Environment (2020a). Australian Ballast Water Management Requirements Version 7. Department of Agriculture, Water and the Environment, Canberra, Australia.

Department of Agriculture, Water and Environment (2020b). Australia's first points of entry for vessels - text version. Department of Agriculture, Water and Environment. https://www.agriculture.gov.au/biosecurity/avm/vessels/first-point-entry-and-non-first-point-entry/seaport-locations [accessed May 2020].

Department of Environment and Energy (2016). Coastal wetlands – mangroves and saltmarsh. Commonwealth of Australia. https://www.environment.gov.au/system/files/resources/e013aa9d-4167-4709-8080-7732950dcc76/files/factsheet-wetlands-mangroves-saltmarshes.pdf [accessed February 2020].

Department of the Environment and New Zealand Ministry for Primary Industries (2015). Anti-fouling and in-water cleaning guidelines. Department of Agriculture, Canberra. CC BY 3.0.

Department of Primary Industry and Fisheries (2013). Indigenous Community Marine Ranger Program. Northern Territory Government report.

Department of Infrastructure, Transport, Cities and Regional Development (2019) Airport Traffic Data. https://www.bitre.gov.au/publications/ongoing/airport_traffic_data [accessed November 2019].

Ditzel Faraco LF, Locks Ghisi C, Marins M, Ota S and Schnell Schühli G (2019). Infestation of mangroves by the invasive moth *Hyblaea puera* (Cramer, 1777) (Lepidoptera: Hyblaeidae). *Brazilian Archives of Biology and Technology*, 62: e19170516.

Duke NC (1988). An endemic mangrove species *Avicennia integra* sp. nov. (Avicenniaceae), in northern Australia. *Australian Systematic Botany*, 1: 177-180.

Duke NC (2006). *Rhizophora apiculate, R. mucronate, R. stylosa, R. x Annamalai, R. x lamarckii* (Indo-West Pacific stilt mangrove). *Species Profiles for Pacific Island Agroforestry*, version 2.1.

Duke NC, Ball M and Ellison J (1998). Factors influencing biodiversity and distributional gradients in mangroves. *Global Ecology and Biogeography*, 7: 27–47.

Duke NC, Kovacs JM, Griffiths AD and Preece LD (2017). Large-scale dieback of mangroves in Australia. *Marine and Freshwater Research,* 68(10): 1816-1829.

Duke NC and Mackenzie J (2018). East Cape York shoreline environmental surveys 2017, a final report to the Commonwealth of Australia. Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) report no. 17/67, James Cook University, Townsville.

Enticott G and Wilkinson K (2013). Biosecurity: whose knowledge counts? Biosecurity: The Socio-Politics of

Invasive Species and Infectious Diseases, London and New York, Routledge: 91- 104.

Food and Agriculture Organisation (FAO) (2020). Fishery and aquaculture country profiles – Australia. http://www.fao.org/fishery/facp/AUS/en [accessed February 2020].

Farnsworth E and Ellison A (1991). Patterns of herbivory in Belizean mangrove swamps. *Biotropica*, 23(4b): 555-567.

Fisheries Research and Development Corporation (2019). Australian fisheries and aquaculture industry 2017/18. Economic and Social Contributions Summary FRDC project 2017-210 *2019*. https://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2017-210-DLD%20Summary.pdf [accessed March 2020].

Gara R, Sarango A and Cannon P (1990). Defoliation of an Ecuadorian mangrove forest by the bagworm, *Oiketicus kirbyi* Guidling (Lepidoptera: Psychidae). *Journal of Tropical Forest Science*, 3(2): 181-186.

Global Commission on Adaptation (2019). Adapt now: a global call for leadership on climate resilience. A report by the Global Center on Adaptation and the World Resources Institute, September 13th 2019. https://cdn.gca.org/assets/2019-09/GlobalCommission_Report_FINAL.pdf [accesses May 2020].

Griffiths B (2019). Deeptime Dreaming, Uncovering Ancient Australia. Schwartz Books Pty. Ltd, Melbourne.

Hulme PE (2009). Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of Applied Ecology,* 46: 10-18.

Inspector-General of Biosecurity (2019). Environmental biosecurity risk management in Australia. Department of Agriculture and Water Resources, Canberra, April. CC BY 4.0.

Jänes H, Macreadie PI, Zu Ermgassesn PS, Gair JR, Treby S, Reeves S, Nicholson E, Ierodiaconou D, Carnell P (2020). Quantifying fisheries enhancement from coastal vegetated ecosystems. *Ecosystem Services*, 43(2020): 101105.

Jenoh E, Robert E, Lehman I, Kioko E, O'Bosire J, Ngisiange N, Dahdouh-Guebas and Koedam N (2016). Wide raging insect infestation of the pioneer Mangrove *Sonneratia alba* by two insect species along the Kenyan Coast. *PLoS One,* 11(5).

Jiang G, Yan Z and Cen M (2000). Insect community and its diversity in Mangrove forests at Yingluo Bay of Guangxi. *The Journal of Applied Ecology,* 11(11): 95-98.

Kruger H, Thompson L, Clarke R, Stenekes N and Carr A (2009). Engaging in Biosecurity: Gap analysis. Bureau of Rural Sciences, Canberra.

Kruger H, Stenekes N, Clarke R and Carr A (2010). Biosecurity engagement guidelines: practical advice for involving communities. Bureau of Rural Sciences, Canberra.

La Manna G, Donno Y, Sarà G and Ceccherelli G (2015). The detrimental consequences for seagrass of ineffective marine park management related to boat anchoring. *Marine Pollution Bulletin*, 90(1-2): 160–166.

Langston A, Kaplan D and Angelini C (2017). Predation restricts black mangrove (*Avicennia germinans*) colonization at its northern range limit along Florida's Gulf Coast. *Hydrobiologica*, 803(1): 317-331.

Larkum WD, Kendrick GA and Ralph PJ (eds) (2018). Seagrasses of Australia- structure ecology and conservation. Springer International Publishing, Switzerland.

Lee S, Primavera J, Dahdouh-Guebas F, McKnee K, O'Bosire J, Cannici S, Fromand F, Koedam N, Marchand C, Mendelssohn I, Mukherjee and Record S (2014). Ecological role and services of tropical mangrove ecosystems: a reassessment. *Global Ecology and Biography,* 23(7): 726-743.

Leon Y (2018). *Cytospora rhizophorae* Kohlm. & E. Kohlm (Valsaceae, Ascomycota) en la República Dominicana. *Ciencia, Ambiente y Clima*, 1(1): 23-31.

Lymburner L, Bunting P, Lucas R, Scarth P, Alam I, Phillips C, Ticehurst C and Held A (2019). Mapping the multi-decadal mangrove dynamics of the Australian coastline. *Remote sensing of Environment*, 238: 111185.

Lui S and Cook D (2016). Eradicate, contain, or live with it? Collaborating with stakeholders to evaluate

responses to invasive species. *Food Security*, 8(1): 49-59.

Marine Education Society of Australasia (2019) Mangroves of Australia. http://www.mesa.edu.au/mangroves/mangroves01.asp [accessed November 2019].

Marine Education Society of Australasia (2020). Seagrasses of Australia. http://www.mesa.edu.au/seagrass/seagrass01.asp [accessed March 2020].

Marine Pest Sectoral Committee (2015). Rapid response manual for *Mytilopsis sallei* and *Perna viridis*. Department of Agriculture and Water Resources, Canberra.

Marine Traffic (2019). Live map. https://www.marinetraffic.com/en/ais/home/centerx:136.8/centery:-21.3/zoom:4 [accessed October 2019].

Mazda Y, Magi M, Kogo M and Hong PN (1997). Mangroves as a coastal protection from waves in the Tong King delta. *Vietnam. Mang. Salt Marsh*, 1(2): 127–135.

McEntee MJ (2007). Participation and communication approaches that influence public and media response to scientific risk: a comparative study of two biosecurity events in New Zealand. The *International Journal of Interdisciplinary Social Sciences,* 2(4):195-203.

Mehlig U and de Menzes M (2005). Mass defoliation of the mangrove tree *Avicennia germinans* by the moth *Hyblaea Puera* (Lepidoptera: hyblaedae) in equatorial Brazil. *Ecotropica*, 11: 87-88.

Mills P, Dehnen-Schmutz K, Ilbery B, Jeger M, Jones G, Little R, MacLeod A, Parker S, Pautasso M, Pietravalle S and Maye D (2011). Integrating natural and social science perspectives on plant disease risk, management and policy formulation. *Philosophical Transactions of the Royal Society of Biological Sciences*, 366: 2035-2044.
NSW Government (2020). Hunter visitor profile – year ending December 2020 factsheet. Destination NSW. https://www.destinationnsw.com.au/wp-content/uploads/2020/04/hunter-fact-sheet-ye-dec-19.pdf [accessed May 2020].

Mccarthy A, Allen WJ and Grant A (2019). Unmanned Aerial Vehicles and biosecurity: enabling participatory-design to help address social licence to operate issues. *Forests*, 10(8): 695.

McGeoch MA, Butchart SH, Spear D, Marais E, Kleynhans EJ, Symes A, Chanson J and Hoffmann M (2010). Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. *Diversity and Distributions,* 16: 95–108.

McKillup C and McKillup RV (1997). An outbreak of the moth *Achaea serva* (Fabr.) on the mangrove *Excoecaria agallocha* (L.). *The Pan–Pacific Entomologist*, 73: 184–185.

Mercer R, McLean F, Dickson J and Mitchell A (2017). Marine pest passive surveillance observer groups-knowledge, reporting behaviour and required education and awareness resources. Instinct and Reason a final report, Kingston, ACT.

Monash University (2007) Explore SahulTime. http://sahultime.monash.edu.au/explore.html [accessed August 2020]

Murphy D (1990). The natural history of insect herbivory on mangrove trees in and near Singapore. *Raffles Bulletin of Zoology,* 38(2): 119-203.

OceanWatch Australia Ltd (2019). (Draft) Gap analysis: education and awareness materials supporting the passive surveillance of marine pests. OceanWatch Australia ref#29377, Sydney.

Onuf CP, Teal JM and Valiela I (1977). Interactions of nutrients, plant growth and herbivory in a mangrove ecosystem. *Ecology*, 58: 514–526.

Osorio J, Crous C, Wingfield M, de Beer W and Roux J (2017). An assessment of mangrove diseases and pests in South Africa. *An International Journal of Forest Research*, 90(3): 343–358.

Osorio J, Wingfield M and Roux J (2016). A review of factors associated with decline and death of mangroves, with particular reference to fungal pathogens. *South African Journal of Botany*, 103(2016): 295-301.

Ozaki K, Kitamura, S, Subiandoro E and Taketani A (1999). Life history of *Aulacaspis marina* Takagi and Williams (Hom., Coccoidea) a new pest of mangrove plantations in Indonesia, and its damage to mangrove

seedlings. *Journal of Applied Entomology*, 123: 281–284.

Ozaki K, Takashima S, Kitamura S and Taniguchi K (2000). Spraying seawater as an effective method to control *Aulacaspis marina* Takagi and Williams (Homoptera:Diaspididae), a mangrove infesting scale insect in Indonesia. *Applied Entomology and Zoology,* 35(2): 287-292.

Perillo G, Wolanski E, Cahoon D and Brinson M (2018). Coastal wetlands: an integrated ecosystem approach 2nd Edition. Elsevier, Dordrecht, Netherlands.

Piola RF and McDonald JI (2012). Marine biosecurity: the importance of awareness, support and cooperation in managing a successful incursion response. *Marine Pollution Bulletin*, 64(9): 1766-1773.

Polidoro BA, Carpenter KE, Collins L, Duke NC, Ellison AM, Ellison JC, Farnsworth EJ, Fernando ES, Kathiresan K, Koedam NE, Livingstone SR, Miyagi T, Moore GE, Ngoc Nam V, Eong Ong J, Primavera JH, Salmo SG, Sanciangco JC, Sukardjo S, Wang Y AND Homg Yong JW (2010). Loss of species: mangrove extinction risk and geographic areas of global concern. *PLoS ONE* 5(4): e10095.

Potter C, Harwood T, Knight J and Tomlinson L (2011). Learning from history, predicting the future: the UK Dutch elm disease outbreak in relation to contemporary tree disease threats. *Philosophical Transactions of the Royal Society B Biological Sciences*, 366: 1966-1974.

Prahalad V (2014). Mapping and inventory of NRM north coastal saltmarshes, natural resource management northern Tasmania, Australia. NRM North Technical Report July 2014, University of Tasmania, Hobart.

Prahalahad V, Woehler EJ, Latinovic A and Mcquillan P (2015). Inventory and monitoring of the birds of Tasmanian saltmarsh wetlands. Bird Observers Association of Tasmania, 2015. https://www.google.com/search?q=Tasmanian+saltmarshes+identified+113+bird+species+associated+with+the+saltmarshes+(Prahalad+et+al.+2015).&rlz=1C1GCEU_enAU827AU827&oq=Tasmanian+saltmarshes+identified+113+bird+species+associated+with+the+saltmarshes+(Prahalad+et+al.+2015).&aqs=chrome..69i57.491j0j8&sourceid=chrome&ie=UTF-8 [accessed May 2020].

Rahaman A (2002). Mangrove insect fauna of Muthupet, Tamil Nadu. National seminar on Conservation of Eastern Ghats, March 24-26 2002.

Reed MS and Curzon R (2015). Stakeholder mapping for the governance of biosecurity: a literature review. *Journal of Integrative Environmental Sciences*, 12(1): 15-38.

Rhainds M and Cabrera-La Rosa J (2010). *Oiketicus kirbyi* (Lepidoptera, Psychidae), a key pest in Peruvian orchards of avocado. *International Journal of Pets Management,* 56(2): 103-107.

Richards C and Higgins V (2016). Trade liberalisation and Australian biosecurity: opportunities and challenges under the 'shared responsibility' approach. *Farm Policy Journal,* 13(3): 1-9.

Robertson AI and Blaber SJM (1992). Plankton, epibenthos and fish communities. In Tropical Mangrove Ecosystems (vol 41). Robertson AI and Alongi DM (eds), American Geophysical Union, Wiley.

Robertson AI and Duke NC (1987a). Insect herbivory on mangrove leaves in North Queensland. *Australian Journal of Ecology*, 12: 1–7.

Robertson AI and Duke NC (1987b). Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. *Marine Biology*, 96: 197-205.

Ronnback P (1999). The ecological basis for economic value of seafood production supported by mangrove ecosystems. *Ecological Economics*, 29(2): 235-252.

Saur E, Daniel I, Etienne J and Mian D (1999). Insect herbivory on mangrove leaves in Guadeloupe: Effects on biomass and mineral content. *Hydrobiologica*, 413: 89-93.

Scion (2018). New weapons in the battle for urban biosecurity. Scions Connections issue 27, March 2018. https://www.scionresearch.com/about-us/about-scion/corporate-publications/scion-connections/past-issues-list/scion-connections-issue-27,-march-2018/new-weapons-in-the-battle-for-urban-biosecurity [accesses June 2020].

Semeniuk V and Cresswell I (2018). Australian mangroves: anthropogenic impacts by industry, agriculture, ports and urbanisation. *Threats to mangrove forests, Coastal Research Library volume,* 25: 173-97.

Serrano O, Lovelock CE, Atwood TB, Macreadie PI, Canto R, Phinn S, Arias-Ortiz A, Bai L, Baldock J, Bedulli C, Carnell P, Connolly RM, Donaldson P, Esteban A, Ewers CJ, Lewis CJE, Eyre BJ, Hayes MA, Horwitz P, Huntely LB, Kavazos CR, Kelleway JL, Kendrick GA, Kilminster K, Lafratta A, Lee S, Lavery PS, Maher DT, Marba N, Masque P, Mateo MA, Mount R, Ralph PJ, Roelfsema C, Rozaimi M, Ruhon R, Salinas C, Samper-Villarreal J, Sanderman J, Sanders CJ, Santos I, Sharples C, Steven AD, Cannard T, Trevathan-Tackett S and Duarte CM (2019). Australian vegetated coastal ecosystems as global hotspots for climate change mitigation. *Nature communications,* 10: 4313.

Short FT, Coles RG and Short CA (2001). Global seagrass research methods. Elsevier, Amsterdam, Netherlands.

Sikes B, Bufford J, Hulme P, Cooper J, Johnston P and Duncan R (2018). Import volumes and biosecurity interventions shape the arrival rate of fungal pathogens. *PLoS Biol,* 16(5): e2006025.

Spalding M and Parrett C (2019). Global patterns in mangrove recreation and tourism. *Marine Policy*, 110(2019): 103540.

Stefan M, Markham C, Benjamin R and Coath J (2013). Case study: invasive insects in plant biosecurity: the Asian Longhorned Beetle Eradication Program *in* The Handbook of Plant Biosecurity. Springer, Dordrecht, 485-517.

Sutcliffe C, Quinn CH, Shannon C, Glover A and Dunn AM (2018). Exploring the attitudes to and uptake of biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in UK natural environments. *Biological Invasions*, 20: 399-411.

Tavares de Menezes LF and Peixtoto AL (2009). Leaf damage in a mangrove swamp at Sepetiba Bay,

Rio de Janeiro, Brazil. *Brazilian Journal of Botany*, 32(4): 715-724.

Tennessen T (2020). 5 Invasive species you should know, *Smithsonian Institute*. https://ocean.si.edu/ocean-life/5-invasive-species-you-should-know [accessed February 2020].

Thomas N, Lucas R, Bunting P, Hardy A, Rosenqvist A and Simard M (2017). Distribution and drivers of global mangrove forest change, 1996–2010. *PLoS ONE,* 12(6): e0179302.

Tong Y, Lee S and Morton B (2006). The herbivore assemblage, herbivory and leaf chemistry of the mangrove Kandelia obovate in two contrasting forests in Hong Kong. *Wetlands Ecology and Management,* 14(1): 39-52.

Weir AM, Tattar TA and Klekowski EJ (2006). Disease of red mangrove (*Rhizophora mangle*) in southwest Puerto Rico Caused by *Cytospora rhizophorae*. *Biotropica*, 32(2): 299-306.

Wells AG (2006). Distribution of mangroves species in Australia. *Biology and ecology of mangroves*, the Hague, Netherlands.

Zhang K, Liu H, Li Y, Xu H, Shen J, Rhome J, Smith III TJ (2012). The role of mangroves in attenuating storm surges. *Estuaries, Coastal and Shelf Science,* 102-103: 11-23.

APPENDIX 1

Table 6: *Global distribution of mangrove species, + = introduced (adapted from Duke et al. 1998) * Mangrove species in bold are found in Australia.*

GENUS	SPECIES	WEST COAST OF AMERICAS	EAST COAST AMERICAS	WEST AFRICA	EAST AFRICA	INDO-MALESIA	AUSTRALASIA
Acanthus	***ebracteatus***					**x**	**x**
	ilicifolius					**x**	**x**
Acrostichum	***aureum***	**x**	**x**	**x**	**x**	**x**	**x**
	danaeifolium	x	x				
	speciosum					**x**	**x**
Aegialitis	***annulata***					**x**	**x**
	rotundifolia					x	
Aegiceras	***corniculatum***					**x**	**x**
	floridum					x	
Aglaia	*cucullata*					x	
Avicennia	*alba*					x	x
	bicolor	x					
	germinans	x	x	x			
	integra						**x**
	marina	**+**			**x**	**x**	**x**
	officinalis					**x**	**x**
	rumphiana					x	x
	schaueiana		x				
Barringtonia	***racemosa***			**x**		**x**	**x**
Bruguiera	***cylindrica***					**x**	**x**
	exaristata						**x**
	gymnorhiza				**x**	**x**	**x**
	hainesii					**x**	**x**
	parviflora					**x**	**x**
	sexangula					**x**	**x**
Camptostemon	*philippinense*					x	
	schultzii						**x**
Ceriops	***australis***						**x**
	decandra					**x**	**x**
	tagal				**x**	**x**	**x**
Conocarpus	*erectus*	x	x	x			
Cynometra	***iripa***					**x**	**x**
Diospyros	***ferrea***					**x**	**x**

GENUS	SPECIES	WEST COAST OF AMERICAS	EAST COAST AMERICAS	WEST AFRICA	EAST AFRICA	INDO-MALESIA	AUSTRALASIA
Dolichandrone	***spathacea***					**x**	**x**
Excoecaria	***agallocha***				**x?**	**x**	**x**
	indica					x	
Heritiera	*fomes*					x	
	globosa					x	
	littoralis				**x**	**x**	**x**
Kandelia	*candel*					x	
Laguncularia	*racemosa*	x	x	x			
Lumnitzera	***littorea***					**x**	**x**
	racemosa			**x**	**x**	**x**	**x**
	x rosea					**x?**	**x**
Mora	*oleifera*	x					
Nypa	***fruticans***		**+**	**+**		**x**	**x**
Osbornia	***octodonta***					**x**	**x**
Pelliciera	*rhizophorae*	x	x				
Pemphis	***acidula***				**x**	**x**	**x**
Rhizophora	***apiculata***					**x**	**x**
	mangle	x	x	x			
	mucronata				**x**	**x**	**x**
	racemosa	x	x	x			
	samoensis						x
	stylosa					**x**	**x**
	x harrisonii	x	x	x			
	x lamarckii					**x**	**x**
	x selala						x
Scyphiphora	***hydrophylacea***					**x**	**x**
Sonneratia	***alba***				**x**	**x**	**x**
	apetala					x	
	caseolaris					**x**	**x**
	griffithii					x	
	lanceolata					**x**	**x**
	ovata					**x**	**x**
	x gulngai					**x**	**x**
	x urama					**x?**	**x**
	alba x ovata					x	
Tabebuia	*palustris*	x					
Xylocarpus	***granatum***				**x**	**x**	**x**

GENUS	SPECIES	WEST COAST OF AMERICAS	EAST COAST AMERICAS	WEST AFRICA	EAST AFRICA	INDO-MALESIA	AUSTRALASIA
	moluccensis					**x**	**x**

Threatened and endangered mangrove species

Table 7: *Mangrove species at risk of extinction (adapted from Polidoro et al. 2010).*

SPECIES	STATUS	AUSTRALIAN SPECIES?
Avicennia bicolor	Vulnerable	No
Avicennia integra	Vulnerable	Yes
Avicennia rumphiana	Vulnerable	No
Tabebuia palustris	Vulnerable	No
Mora oleifera	Vulnerable	No
Sonneratia griffithii	Critically endangered	No
Camptostemon philippinense	Endangered	No
Heritiera fomes	Endangered	No
Heritiera globosa	Endangered	No
Bruguiera hainesii	Critically endangered	Yes – (discovered in Cairns Trinity Inlet in 2016)
Pelliciera rhizophorae	Vulnerable	No

APPENDIX 2

Risk pathway analysis: supporting information

Table 8: *Australian import statistics for 2016-17 (data sourced from Ports Australia 2019).*

IMPORT	TOTAL FOR ALL PORTS*	TOTAL FOR PORTS IN CLOSE PROXIMITY TO MANGROVES**	NT	SA	WA	QLD	VIC	NSW	TAS
Total import throughput (tonnes)	82,755,693	39,243,030	1,355,314	7,976,220	20,957,288	25,796,372	20,822,576	5,847,923	-
Motor vehicles (units)	508,344	20,895	6,180	46,454	93,211	14,715	347,784	0	-
Container cargo- full (TEU)	1,795,841	59,530	10,597	145,839	344,028	48,430.25	1,246,498	449	-
Container cargo – empty (TEU)	229,820	41,418	635	49,209	30,077	36,161	109,116	4,622	-

*Ports with data available. Includes Darwin, Port Adelaide, Klein Point, Port Giles, Port Pirie, Port Lincoln, Thevenard, Wallaroo, Freemantle, Gladstone, Alma, Bundaberg, Kimberly, Port Melbourne, Mid West Ports, Newcastle Port, Port of Portland, Cairns Port, Mourilyan Port, Cape Flattery Port, Thursday Island, Karumba, Port Headland, Dampier, Port of Albany, Port of Bunbury, Port of Esperance, Townsville, Lucinda, Sydney Harbour, Port Botany, Port of Eden, Yamba

**Ports in close proximity to mangroves with available data: Darwin, Port Pirie, Gladstone, Alma, Bundaberg, Broome, Newcastle, Cairns, Mourilyan, Thursday Island (Port Kennedy), Karumba, Port Headland, Dampier, Bunbury, Townsville, Lucinda, Port Botany, Eden, Yamba, Sydney harbor

***TEU = Twenty-foot Equivalent Unit

Table 9: *Vessel landings at Australian ports according to vessel type (data sourced from Ports Australia 2019).*

VESSEL CALLS (NUMBER)	TOTAL FOR ALL PORTS*	TOTAL FOR PORTS IN CLOSE PROXIMITY TO MANGROVES**	NT	SA	WA	QLD	VIC	NSW	TAS
Navy	356	243	79	8	150	55	10	54	-
Cruise ship	707	567	75	35	156	68	10	363	-
Commercial	22,986	15,684	1,075	1,929	9,745	3,098	2,910	4,229	-

Table 10: *Breakdown of cargo contents for commercial vessels entering Australia in 2016-17 (data sourced from Ports Australia 2019).*

CARGO BREAKDOWN (NUMBER)	TOTAL FOR ALL PORTS*	TOTAL FOR PORTS IN CLOSE PROXIMITY TO MANGROVES**	NT	SA	WA	QLD	VIC	NSW	TAS
Container	3,431	1,382	50	412	526	163	1,111	1,169	-
Bulk liquid	1,772	1,442	44	139	412	275	255	647	-
Bulk gas	852	835	66	0	418	343	0	25	-
Dry bulk	10,519	7,735	17	1,121	5,244	1,596	448	2,093	-
Car carrier	793	76	15	127	217	61	373	0	-
Livestock carrier	280	192	119	4	83	53	20	1	-
General cargo	4,774	3,422	764	126	2,801	95	703	285	-

Table 11: *Australian inbound air freight, mail and craft statistics 2017-18 (Department of Infrastructure, Transport, Cities and Regional Development 2019).*

AIRPORT	INBOUND INTERNATIONAL AIR FREIGHT (TONNES)	INBOUND INTERNATIONAL AIR MAIL (TONNES)	DOMESTIC AIRLINE AIRCRAFT INBOUND MOVEMENTS (INCLUDING REGIONAL FLIGHTS)	INTERNATIONAL AIRLINE AIRCRAFT INBOUND MOVEMENTS
Adelaide	14,400	0	36,605	2,470
Brisbane	61,496	1628	18,512	16,766
Cairns	488	42	21,181	2,682
Gold Coast	6,693	53	17,977	3,256
Sunshine Coast	0	0	4,163	55
Canberra	518	0	19,370	537
Darwin	360	0	11,998	1,181
Melbourne	146,932	6,695	96,012	24,714
Perth	45,242	768	34,862	11,341
Sydney	305,922	17,408	120,212	39,863
Australian total	582,168	26,595	633,622	103,169

APPENDIX 3

Stakeholders consulted and case studies

Understanding the case-study locations

A list of stakeholders and their interactions with mangrove communities for the three case study locations has been provided in Tables 3-6.

Cairns

Cairns is located in the tropics of far north Queensland (QLD). The surrounding regional areas are dominated by sugarcane, cattle production, tropical fruit production and protected areas. The Cairns community is diverse and tourism, farming, fishing and health services are the major industries. Cairns is situated between two significant United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Sites; the Great Barrier Reef and the Wet Tropics of Queensland.

The Great Barrier Reef is an important icon in the Australian psyche and economy. The Great Barrier Reef contributes a value of $56 billion dollars to the Australian economy and supports ~64,000 jobs (Deloitte Access Economics 2017). The mangroves in Cairns and surrounding regions are recognised for their importance as a buffer for the health of the Great Barrier Reef, slowing and filtering agricultural, urban and industrial runoff from the surrounding landscape, and protecting the reef from the full effects of human development (Goudkamp et al. 2006).

The beaches, estuaries, and creeks in and around Cairns are lined with mangroves, mainly *Avicennia* and *Rhizophora* species. The council operate a mangrove removal program along the esplanade beach front to maintain the city's ocean view. Large seagrass meadows grow in Cairns Harbour and surrounding waters. The seagrasses in Cairns Harbour, primarily of *Zostera muelleri*, *Cymodocea serrulata*, *Halodule uninervis, Halophila ovalis* and *Halophila decipiens* have been monitored annually since 2001 in a partnership between James Cook University (JCU) and Ports North (Reason and Rasheed 2018).

Cairns is a popular tourist destination for international and domestic holiday makers alike and is known in marketing parlance as the gateway to tropical north Queensland. In 2018, 42% (or 790,000) of visitors to Cairns were international tourists (Tourism Research Australia 2018)[12]. Visitors come from all over the world but tourists from China, Japan, America, Britain, Canada and India make up the largest proportion of international visits. As at November 2020, the Cairns international airport was receiving direct flights from Bali, Singapore, Hong Kong, Shenzhen, Shanghai, Osaka, Tokyo, Port Moresby, Apia and Auckland (flight arrivals from other international locations occurred intermittently) (Table 1).

Table 1: *Scheduled international arrivals to Cairns international airport for 2019-20[13] (data from Cairns airport).*

Departure country	Scheduled flight arrivals 2019-20
Papua New Guinea	1166
Japan	584
Indonesia	181
Singapore	171
New Zealand	98
Samoa	59
China	49
Hong Kong	7
Total flights	2315

[12] This overview of Cairns as a tourist destination has been provided as it was before the COVID 19 pandemic. Cairns remains a popular destination for holiday makers but as of 2021, international arrivals have almost completely ceased.

[13] Table 1 presents the flights scheduled for 2019-20 as of November 2019. Due to travel restrictions relating to the COVID-19 pandemic, the actual flight statistics for 2020 were much reduced.

Cairns is a popular first port of call for many itinerant vessels including superyachts and cruise liners. In 2018-19, 62 cruise liners docked at the Port of Cairns (includes domestic cruise ships) (Douglas et al. 2018). Many of these cruise liners arrived directly from an international port (Table 2). The trend in cruise liner tourism is projected to rise, and a planned expansion of the Port of Cairns was[14] predicted to triple cruise liner tourism from 2018 to 2030 to reach an estimated 183 cruise ships per year by 2031 (Douglas et al. 2018).

These characteristics of Cairns as a hub of international tourism with plans to further develop the port are likely to increase the risk of exotic biosecurity incursions in the region.

Table 2: *Cruise liners arriving to the Port of Cairns directly from an overseas port in 2018 and 2019 (data from Ports North 2020).*

Arrival date	Vessel	Arriving from	Next destination	Passenger capacity
2018				
8 Feb	Asuka II	Saipan (Japan)	Sydney	1110
16 Feb	Artania	Port Moresby	Townsville	1260
3 May	Sun Princess	Alotau (Papua New Guinea)	Darwin	2010
3 Aug	Pacific Eden	Conflict Is (PNG)	Alotau (PNG)	1500
7 Aug	Pacific Eden	Conflict Is (PNG)	Conflict Is (PNG)	1500
17 Aug	Pacific Eden	Honiara (Solomon Is)	Alotau (PNG)	1500
24 Aug	Pacific Eden	Conflict Is (PNG)	Willis Island	1500
26 Aug	Pacific Aria	Dili (Timor)	Airlie Beach	1500
6 Sept	Pacific Eden	Honiara (Solomon Is)	Townsville	1500
17 Nov	Coral Discoverer	PNG	TRS	72
2 Dec	Coral Discoverer	PNG		72
5 December	Seabourn Sojourn	Conflict Is (PNG)	Townsville	462
2019				
21 March	Maasdam	Dili (Indonesia)	Alotau (PNG)	1258
12 May	Le Laperouse	Samari Is. (PNG)	Cape York	185
24 May	Island Sky	Port Moresby (PNG)	Broome	228
10 Oct	Sea Princess	Alotau (PNG)	Darwin	2016
22 Oct	Sun Princess	Alotau (PNG)	Darwin	2010
30 Oct	Coral Adventurer	PNG	PNG	120
24 Nov	Coral Adventurer	PNG	PNG	120
27 Nov	Maasdam	Conflict Is (PNG)	Townsville	1258

Traditionally owned land between Yarrabah and Black Mountain, North Queensland

This project explored the biosecurity and stakeholder context surrounding mangrove communities in the lands of the Mandingalbay Yidinji, Kuku Yalanji and Yirrganydji people. The Mandingalbay Yidinji people are the Traditional Owners of the land at Yarrabah, the Kuku Yalanji are the Traditional Owners of the country between Cairns (Trinity Beach) and Port Douglas and the Yirrganydji are the Traditional Owners of the country between Mossman and Black Mountain. These groups hold the Native Title to at least part of their

[14] Predictions based on pre-COVID 19 industry planning.

traditional lands.

Mangrove species diversity in this region is high with 29 species represented in Mossman and 39 mangrove species and hybrids in the Daintree region (Goudkamp 2006). Twenty-six species of saltmarsh occur along this stretch of the Queensland coast (Goudkamp et al. 2006). The traditional hunting of dugongs and sea turtle is an important cultural activity in the study area as these animals are supported by the 19 seagrass species that grow around Cairns and Port Douglas. The Traditional Owners of these sea country regions have expressed their concern regarding the degradation of these ecosystems and the risk that this poses to shorebird, crocodile, whale, dolphin, and fish populations (Dawul Wuru Aboriginal Corporation 2014). The effects of sedimentation, pollution and climate change are particular drivers of concern to Traditional Custodians.

The Mandingalbay Yidinji, Kuku Yalanji and Yirrganydji groups each operate a ranger group under the Caring for Country program. Indigenous rangers are the Traditional Owners of the lands that they manage and as such have the authority to undertake land management activities on their lands. The Indigenous rangers also play a fundamental role in obtaining the appropriate approvals for management activities from other community members with decision-making authority over specific aspects of the land and sea. Decision-makers include community Elders, community members of the relevant totem, or community cultural committees and boards.

Indigenous ranger groups receive base-funding but are expected to obtain project funding from governments, universities, and other land management organisations in order to expand activities. The Indigenous ranger groups, including the Djunbunji at Yarrabah, are involved in biosecurity surveillance activities and can provide assistance to biosecurity agencies during an emergency response. The NAQS program engages directly with several indigenous groups across northern Australia in marine, plant and animal biosecurity activities. The program has trained local people in the identification of exotic pests and protocols for sample collection. This training has resulted in several community reports, including marine pest specimens from beached rafts and the detection of Asian Green Mussels on Mornington Island in 2019.

The primary exotic biosecurity risk to this part of the country is international tourism through the Cairns international airport, itinerant vessels, imports and cruise liners.

Newcastle

Newcastle is a coastal city located 160 km north of Sydney. Historically, Newcastle was known as an industrial town with significant coal mining and fishing operations supported by its large port. Industry remains a key feature in Newcastle and the Port of Newcastle continues to be the busiest coal port in Australia. The Port of Newcastle is also a busy grain, alumina and agricultural export hub that berths an average of 2,200 international vessels each year (Jackie Spiteri pers. comm., 2019). The Port of Newcastle has recently received a $33 billion upgrade to accommodate the continued demand for Australian exports (Port of Newcastle 2019).

The Hunter River meets the ocean at Newcastle and dense mangrove forests line its banks around the city and further upstream. The City of Newcastle Council is responsible for maintaining 65 wetlands, 8 kilometres of river wall and 79 kilometres of creek (City of Newcastle 2019). Two mangrove species grow in the temperate conditions of Newcastle, the grey mangrove (*Avicennia marina*) and the river mangrove (*Aegiceras corniculatum*). Saltmarsh grows at various locations including Kooragang wetlands, Hexham Swamp, Tomago Wetlands and Ash Island and extensive seagrass meadows grow offshore (Burns and Davey 2010). These ecosystems are vital to the fishing industries and recreational fishers of the region, supporting local fish populations including bream, blackfish and mullet.

Historically, the mangrove and saltmarsh areas in Newcastle were often used as rubbish dumps. Extensive degradation of these ecosystems also occurred through clearing, draining, filling and dredging activities (Herbert 2007). Hunter Local Land Services estimates that 80% of saltmarsh and 21% of mangrove area has disappeared from the Hunter River Wetlands in the past 200 years since European settlement (Hunter Local Land Services 2016).

Despite this, the Hunter River Wetlands are internationally recognised as a listed Ramsar wetland. In an effort to restore previously degraded wetlands, rehabilitation work has been undertaken at Throsby Creek, Ash Island and the Kooragang Wetlands. These mangroves are now valued for their recreational and amenity value, though poor water quality and clearing for urban development remain a threat for mangroves in

Newcastle.

Tourism is not a main feature of Newcastle though in 2019 the Hunter Region, including the wine regions and surrounding summer holiday towns received 195,000 international visitors and 4.6 million domestic overnight visitors (NSW Government 2020). Twenty three percent of visitors to Newcastle arrive through cruise liner tourism (Tourism Research Australia 2013). The Newcastle Cruising and Yacht Club receives fewer first port of entry traffic when compared with Cairns with an average of one superyacht arrival every two months from an international port (Sandy Hapgood pers. comm., 2019).

The port provides the main exotic biosecurity risk for mangrove communities in Newcastle. Biofouling and hitchhiking pests were identified as primary pathways for exotic species introductions. Pests or pathogens could find favourable hosts in the adjacent mangrove, saltmarsh and/or seagrass communities. The Port of Newcastle does not currently have any surveillance programs in place (e.g. settlement plates) for the detection of exotic marine pests.

In NSW, the management of fish and marine vegetation is legislated under the *Fisheries Management Act 1994* and is the responsibility of NSW Department of Primary Industries (DPI). Any activity which may cause harm to mangrove, seagrass or saltmarsh (or any other marine vegetation) in NSW must be referred to NSW DPI for approval. Saltmarsh in NSW is listed as an Endangered Ecological Community and as such, any activity that is likely to cause significant harm to saltmarsh is unlikely to be approved if the potential for harm cannot be mitigated.

Who are the stakeholders of mangrove community biosecurity?

Mangroves and their associated communities underpin a wide variety of socio-economic interests and values. Thus, the stakeholders that may be impacted by a new pest to mangrove communities are many, diverse and often context specific.

To understand the stakeholder context at each case study location, PHA travelled to Cairns, East Trinity Inlet and Newcastle to meet with stakeholders face-to-face. PHA also engaged with interested parties at a national scale through email, phone and face-to-face meetings to better understand the broader context for mangrove community biosecurity. All identified stakeholders are included in the Tables 8-11 (below).

Key messages arising from stakeholder consultations were considered and informed recommendations where appropriate.

Cairns mangrove stakeholders

Table 3: *List of stakeholders and existing relevant activities associated with mangrove communities in Cairns.*

Stakeholder	Association	Existing activities within mangrove communities
Adventure North Australia	Tourism operators.	• Operates tour groups in mangrove community environments including boat trips in Daintree and Cooktown
Asia-Pacific Superyacht Association (APSA)	Professional yacht industry association for the Asia-Pacific region. Has a role in promoting superyacht businesses and industry.	• No direct activities
Australian Institute of Marine Science (Townsville)	Provides multi-disciplinary research with a goal to provide better decision-making by governments, industry and the community concerning marine environments.	• Research projects including the investigation into condition of coastal environments and the effects that this has on the GBR • Water quality monitoring • Two research vessels deployed in coastal and marine environments
Australian Superyacht Services	Organises services for and provides information to superyachts including fuel, marinas, and other shipyard services.	• No direct activities • Communication with superyachts
Australian Tropical Herbarium	Research and activities within mangrove ecosystems. Biosecurity/invasions research flagship recently established at JCU, Cairns.	• Regional ecosystem mapping project (includes mangrove area mapping) - data collected every two years
Biosecurity Queensland	Biosecurity preparedness, response and management responsibilities.	• Marine pest preparedness program, including; - marine pest surveillance program - public education and awareness program - emergency response simulation exercises - Indigenous rangers marine pest surveillance program

Stakeholder	Association	Existing activities within mangrove communities
BirdLife Northern Queensland	Local branch of BirdLife Australia. Advocates and promotes birdwatching and the protection of birds and their habitats.	• Bird monitoring activities in Important Bird Areas • Educational and recreational activities in coastal habitats
Cairns Adventure Group	Tourism business operating mangrove tours and water/boating activities.	• Some tourism activities in estuaries
Cairns and Far North Environment Centre (CAFNEC)	Peak environmental group for Far North Queensland, advocacy, community education and support for local environment and conservation activities. CAFNEC acts as a conservation council and coordinates a range of citizen-science programs.	• Coordinates the Cairns MangroveWatch group which documents issues and area change in Trinity Inlet, Barron River and all estuaries around Cairns • Community education tours on Cairns mangrove boardwalk (when open) • Collects data for Wet Tropics report card, including 10 saltmarsh survey sites • Beach, estuary, and mangrove clean-ups along with ReefBlitz, Tangaroa Blue and Parley
Cairns Botanic Gardens	Conservation, education, and species preservation. Cairns Botanic Gardens employ a range of staff with relevant interests and useful skills.	• Gardens include a saltwater lake and mangrove area
Cairns Local Marine Advisory Panel	Local group of interested citizens formed to discuss issues of concern relating to the marine environment. The Cairns Local Marine Advisory Panel meets with and feeds issues through to the GBR Marine Park Authority.	• Recent activities include the screening of short-film 'Waterway Warriors' which raise awareness about caring for the Cairns waterways • Raised concerns around the need for improved communication across agencies regarding biosecurity issues for the reef • Raise concerns with regard to sediment runoff during monsoons and the impact of this on water quality and seagrass beds • Promoted the importance of biosecurity in the Reef 2050 Plan
Port of Cairns (Ports North)	Manages boat arrivals and departures from Cairns marina. Relevant due to association with biosecurity risk creators and	• Ports North Pilots board vessels to guide them into port, but would not look out for any biosecurity concerns on

Stakeholder	Association	Existing activities within mangrove communities
	proximity to mangroves and aquatic activities.	ships • If there is a particular biosecurity risk or regulation change, QDAF communicate to Ports North and Shipping agents communicate to the cargo companies • Workers on slipways handle biofouling waste • Ports North partner with QDAF who manage settlement plates in their operating zones • Baseline vegetation mapping around some ports e.g. Mourilyan. • Funds JCU to undertake seagrass mapping (by helicopter and boat) which includes measurements such as density, area change and algal composition • Regular trimming of mangroves surrounding the port with permit from QDAF
Cairns Regional Council	Biosecurity operations and weed management activities. Organise and supervise community volunteer gardening and environment groups.	• Some construction and land use regulation activities relating to mangroves • Manages the Jack Barnes Mangrove Boardwalk (currently closed) • Coordinates volunteer groups which work in proximity to mangrove ecosystems
Cairns Reef Fishing	Fishing tourism company.	• No direct activities
Cape York Tours	Tour group operators. Some tour destinations in remote coastal ecosystems on Cape York.	• No direct activities
Carter Marine Services	Service provider for superyachts.	• No direct activities
Coral Expeditions	Cruise tourism operators. Relevant due to risk creation by operating cruising vessels which stop at multiple destinations domestically and internationally.	• No direct activities
Department of Environment	Includes Queensland National Parks and Daintree National Park.	• Mangrove and wetland mapping and diversity studies[15]

[15] For more information see https://wetlandinfo.des.qld.gov.au/wetlandmaps/ and https://wetlandinfo.des.qld.gov.au/wetlands/facts-maps/

Stakeholder	Association	Existing activities within mangrove communities
and Science	Manages volunteer and ranger activities and conduct wetlands health research projects.	• National Park land management activities
Great Barrier Reef Foundation	Funds research projects and organises activities focused on the protection and preservation of the GBR.	• Facilitate results collection for water quality improvement report card in Mulgrave-Russell, Johnstone and Tully, Upper Herbert, Lower Herbert, Lower Burdekin, Upper Burdekin, East Burdekin, Bowen Broken Bogie, Pioneer/Plane Creek, Lower Fitzroy, Mackenzie and Mayr catchments • Supports ReefBlitz - annual citizen science data collection and debris clean-up campaign
Great Barrier Reef Legacy	Coordinates and assists with a range of citizen science and science projects to support the health of the GBR including health monitoring, community awareness information nights, biodiversity surveys and storm damage rehabilitation.	• MangroveWatch health and monitoring activities • Seagrass mapping activities • Various activities to support research projects on the GBR including sea vessel expeditions
Great Barrier Reef Sport Fishing Charters	Fishing tourism operators.	• No direct activities
Holloways Beach Environmental Education Centre	Organises school camps and specially designed school workshop programs to educate primary and secondary school students about the environment and biological science methods.	• Hands-on education programs to assess water quality and mud crab counts, riparian health assessments, fish, bird and yabby biodiversity counts • Mangrove plant and animal study programs • Mangrove Watch surveys • Estuary boat trips and monitoring
James Cook University - TropEco Sustainability Club	Sustainability and environmental protection group. Undertakes a range of sustainability projects including volunteering with CAFNEC and flora and fauna surveys.	• No direct activities
Mulgrave Landcare and Catchment	Revegetation projects, tree corridors and wetlands.	• No direct activities
MangroveWatch (Cairns)	Citizen-science monitoring of mangrove health in the Cairns local area.	• Mangrove health and mapping surveys undertaken a few times a year.
Marine Teachers Association of	Partnership of members to foster curiosity and learning of school-aged students in marine ecosystems. The Marine Teachers	• Schools at Gladstone, Cairns and Mackay have agreed to

Stakeholder	Association	Existing activities within mangrove communities
QLD	Association facilitates curriculum exchange, workshops, learning programs, conferences and professional development programs.	adopt a MangroveWatch for schools curriculum
Melanesian Yacht services	Yacht and superyacht support.	• No direct activities
Northern Australia Quarantine Strategy (NAQS)	Exotic biosecurity surveillance activities.	• Inspections of abandoned and foreign fishing vessels • Surveys and biosecurity advice for local agencies and Biosecurity Queensland • Support for Indigenous Ranger Groups conducting biosecurity surveillance activities in the littoral zone
Reef Citizen Science Alliance	Partners volunteers with science projects for data collection on various biodiversity and ecosystem health projects.	• Organises and supports around 47 beach clean-up and catchment restoration projects annually including Cairns saltmarsh mapping (together with CAFNEC)
Reef Restoration Foundation	Not for profit social enterprise to establish a number of offshore coral nurseries throughout the GBR.	• No direct activities
Superyacht group (Great Barrier Reef)	Information source and links to superyacht service providers. Provides information for quarantine requirements and agencies.	• No direct activities
Superyacht logistics	Yacht and superyacht support.	• No direct activities
Superyacht training and recruitment	Superyacht crew training.	• No direct activities
Terrain NRM	On-ground activity with farmers, Traditional Owners and community to improve the environments of the Wet Tropics region, including water quality improvement and monitoring. Provides funding for local community group projects.	• Various on-ground land management activities in relevant ecosystems
Tourism Tropical North Queensland	Promotes north Queensland as a tourism destination. Relevance is through reliance on healthy ecosystems and links with a range of groups and service providers that are stakeholders of mangrove communities.	• No direct activities
TropWATER (JCU)	Aquatic research centre within JCU which includes the Mangrove Hub and MangroveWatch research team.	• Various research projects including: - Coastal Habitat Archive and Monitoring Program (including aerial and field surveys identifying ecosystems, changes

Stakeholder	Association	Existing activities within mangrove communities
		and the drivers of change) - Mangrove and saltmarsh plant species surveys - Wetland Cover Index (tidal vegetation mapping and condition evaluations) - Shoreline Video Assessment Method (baseline and on-going evaluations of shoreline status and condition) - Long Plot Method (assessments of structure, biodiversity and biomass of mangrove forests) - Mangrove sediment coring for carbon content analysis, analyses of mangrove forest structures (age, canopy density and seedling regrowth) and productivity (litterfall and shoot growth) - Mangrove storm damage evaluations - Estuarine and Coastal Shoreline Report Cards
Wet Tropics Management Authority (WTMA)	Oversees 900,000 ha of UNESCO World Heritage land, of which is 1.7% is mangroves. WTMA is not the land manager but regulate activities in the area including Indigenous rangers, community volunteer groups, Green Army, Landcare and work for the dole. Projects include eradication of yellow crazy ants, student research grants and, Rainforest Aboriginal Grants.	• No direct activities but manages groups who conduct activities within and around the mangrove area

Mangrove stakeholders of traditionally owned land between Yarrabah and Black Mountain, North Queensland

Table 4: *List of stakeholders and existing relevant activities associated with mangrove communities on the traditionally owned land of the Mandingalbay Yidinji, Eastern Kuku Yalanji and Yirrganydji people.*

Stakeholder	Association	Existing activities within mangrove communities
Mandingalbay Yidinji people (Yarrabah)		
Mandingalbay Yidinji Corporation	Representative body of the Mandingalbay Yidinji people at Yarrabah. Holds the Native Title and manages cultural responsibilities.	• Oversees ranger activities • Operates tourist group tours within estuaries and mangrove habitats
Cultural Protocol Committee	A committee of Mandingalbay Yidinji representatives who ensure that the activities of the rangers and other land management activities are culturally appropriate and align with community priorities.	• Oversight of ranger program and community activities
Djunbunji Land and Sea Program	Ranger group at East Trinity Inlet.	• Land and waterways management including sea debris removal, feral animal control, weed data collection and removal • Previous mangrove re-planting work and waterway remediation • Biodiversity surveys in partnership with research projects • Beach clean-ups, turtle and dugong monitoring and compliance
Mandingalbay Yidinji Traditional Owners	Local community of Traditional Owners at Yarrabah.	• Traditional use. Fishing, boating, collecting mud crabs and cultural education activities • Assistance in collecting mangrove propagules for mangrove replanting projects
Yarrabah Aboriginal Shire Council	Local council and public administrative responsibilities. This includes the responsibility for fisheries.	• Oversight of fisheries
Yirrganydji people (Cairns Trinity Inlet to Port Douglas)		
Dawul Wuru Aboriginal Corporation	Represents and the Yirrganydji people and holds the Native Title to their lands. Activities include oversight of the Traditional Use of Marine Resources Agreement (TUMRA), the Estuarine Crocodile Monitoring Program and the Yirrganydji Land and Sea Ranger Program.	• Oversight of activities
Dawul Wuru Aboriginal Corporation – estuarine crocodile monitoring and	Traditionally owned, crocodile monitoring and capturing service for the coastline between Cairns' Trinity Inlet and Ellis Beach.	• Regular crocodile monitoring in local estuaries

Stakeholder	Association	Existing activities within mangrove communities
capture service		
Yirrganydji Ranger Program	Ranger group for Yirrganydji land (Cairns to Port Douglas). Undertakes work for a range of environmental management plans, including those for Queensland National Parks and Great Barrier Reef Marine Parks Association.	• Biodiversity surveys, invasive species control, and activities to protect turtles and dugongs • Marine park management and compliance activities • Monitoring of storm damage on islands, crown of thorn and bird monitoring activities • Management of traditional use of marine resources e.g. turtles and dugongs
Yirrganydji Traditional Owners	Traditional Owners of the land from Cairns (Trinity Inlet) to Port Douglas.	• Community living adjacent to mangrove ecosystems • Collecting pipis, long beach palm, mud crab, mangrove mussels and fishing
Kuku Yalanji people (Mossman to Black Mountain)		
Jabalbina Yalanji Aboriginal Corporation	Representative body for the Yalanji people. Responsible for managing culture and environment with the Yalanji people.	• Oversight of the Jabalbina Ranger Program
Jabalbina Ranger Program	Ranger group based at Mossman, Ayton and Shipton's Flat which manages the land and sea area under Eastern Kuku Yalanji Indigenous Protected Area. The Rangers are looking to develop endemic species inventories.	• Beach and river clean-ups, land and sea monitoring activities and revegetation work • Have recently secured a boat to conduct independent sea monitoring activities
Traditional Owners Negotiation Committee	Committee to represent and make decisions on behalf of and appropriate for the Eastern Kuku Yalanji people. Rangers and universities must get approval from the Traditional Owners Negotiation Committee before undertaking any new work.	• Oversee some field activities and participate in some botanical surveys, matching language names with latin names
Kuku Yalanji Traditional Owners	Yalanji Traditional Owners on lands from Mossman to Black Mountain.	• Traditional harvest • Fishing, collecting mud crabs

Newcastle mangrove stakeholders

Table 5: *List of stakeholders and existing relevant activities associated with mangrove communities in Newcastle.*

Stakeholder	association	existing activities within mangrove communities
Awabakal Local Aboriginal Land Council	Representing the Awabakal Traditional Owners of the land from Wollombi to Newcastle and up to Lake Macquarie. The council represents the interests of the Traditional Owners and works to preserve and restore culture and heritage in the region. The council provides a number of services including culture and heritage assessments, housing, smoking ceremonies and education programs.	• No direct activities • Works with the community who are stakeholders and undertake activities within mangrove ecosystems
B and L Fishing and Cruises	Fishing charter for groups.	• No direct activities
City of Newcastle Council	Local council responsible for management activities surrounding mangrove communities.	• Mangrove area on crown land now under council management • Boat ramps and tide gates under council management • Funding of mangrove rehabilitation projects including Throsby Creek and Throsby Creek boardwalk • Council staff involved in drainage rehabilitation, city greening, management of bushland parcels, channel maintenance and ecological survey activities • Discuss mangrove removal for development plans
Commercial Fisherman's Cooperative	Amalgamates fish catches for retail and wholesale. Engages with OceanWatch Australia projects.	• No direct activities
Conservation Volunteers Australia (Newcastle)	Organises volunteer programs for conservation efforts.	• No direct activities
Hunter Bird Observers Club	Hunter Bird Observers Club has 350 members involved in regular bird-watching, biodiversity mapping and restoration projects. Bird-watching activities are conducted in mangrove habitats around the Hunter Wetlands National Park.	• Monthly surveys of birdlife along the Hunter River Estuaries including tidal mudflats and sandflats. All data feeds into a database which has been running since 1999 • Bi-annual surveys of Port Stephens waterbirds. Monthly surveys of shorebird and waterbirds at Lake Macquarie entrance • Ongoing volunteering in the Hunter Estuary restoration works to preserve and increase shorebird habitat. Activity at Stockton Sandspit, Ash Island, Smith Island, Sandy Island, Fullerton Cove Beach and Dyke Pond • Involvement in various other short- and long-term research

Stakeholder	association	existing activities within mangrove communities
		projects including recent three month trial of drones to survey birdlife at Hexham Swamp and Tomago Wetlands • Previous involvement in a three-month intensive survey and observation effort to ensure the recovery of saltmarsh at Ash Island after a bushfire in 2012
Hunter Cargo and Customs	Freight forwarding company. Relevance due to association with risk creation.	• No direct activities
Hunter Community Environment Centre	Advocacy and education for the Newcastle and the Hunter region. Mobilises community volunteers on local environmental issues. Work includes campaigns for improved air quality, controls on heavy metals draining into Lake Macquarie, zoning of marine sanctuaries in the Port Stephens area, assessing NSW fishing catch data to determine sustainability and establishing the Coal Terminal Action Group.	• Some volunteer activities within mangrove habitats e.g. kayaking, bird feather collecting, water quality testing
Hunter Local Land Services	Supports NSW DPI in biosecurity activities. Hunter Local Land Services has a community extension and awareness role, engaging with local groups and is involved in some management activities in Kooragang Wetlands.	• Management activities in the Hunter Wetland area including restoration and site health monitoring
Hunter Wetlands Centre	The Hunter Wetlands Centre is a community-run centre involved in rehabilitating and now managing 45 ha of wetlands. The Hunter Wetlands Centre has 700 members and 150 weekly volunteers who assist with land management activities. The Hunter Wetlands Centre has an education centre for school students and a nursery which propagates and sells plants.	• Wetland land management • Community awareness and volunteer programs • Mangrove boardwalk and community and school groups fishing and activities in the mangroves
Kooragang Landcare Volunteers	Local community volunteer group interested in restoring and preserving the native habitat of the Kooragang and Hunter River Estuary.	• Monthly revegetation activities, biodiversity surveys and weed control
Kooragang Wetlands Rehabilitation Project	Kooragang Wetlands Rehabilitation Project rehabilitated an industrial waste site into intertidal and tidal wetland conservation site. Management of the site involves a partnership between the NSW Office of Environment and Heritage, NSW DPI, Hunter Local Land Services, University of Newcastle, Kooragang Landcare	• Revegetation and weed control • Maintenance of walking tracks and boardwalks through mangrove and saltmarsh communities • Research trials tracking saltmarsh retreat, biodiversity supported by mangroves and ecosystem health

Stakeholder	association	existing activities within mangrove communities
	volunteers and Hunter Bird Observers Club. The site includes Kooragang City Farm which is a permaculture food forest and educational site.	
Marine Parks Association	The Marine Parks Association provides advocacy and community awareness for issues affecting aquatic health in the Port Stephens region. Coordination of various citizen-science projects including dolphin counts, beach profiling, and sustainable fishing education. The Marine Parks Association has expressed an interest in partnering with NSW DPI and the Office of Environment and Heritage on projects to map seagrass, sea urchin numbers, recreational fishing surveys and marine debris collection and monitoring.	• No current activities
Nature Conservation Council of NSW	Engages in advocacy, education and organising volunteers for campaigns to protect critical habitat and native species, including marine life.	• No direct activities
Newcastle Coal Infrastructure Group	The Newcastle Coal Infrastructure Group operates a coal export terminal located on Kooragang Island, directly adjacent to large sections of mangrove habitat. The company has an interest in managing the impacts from their operation. They conduct regular monitoring of air quality, dust deposition, ground water and surface water as part of their requirements to the Environmental Protection Authority. The Newcastle Coal Infrastructure Group has previously funded activities to offset the impacts of their business, e.g. through university research into the protection of the green and golden bell frog and habitat restoration for migratory shorebirds.	• Water quality monitoring in mangrove habitats
Newcastle Community Consultative Committee on the Environment	Represents the community on local environmental issues and communicates concerns to the Newcastle Local Government. Efforts are undertaken to work with local industry to help them better understand the community's concerns.	• Advocacy for local environmental concerns
Newcastle Cruising Yacht Club	Newcastle Cruising Yacht Club leases moorings to vessels and facilitates service provision for vessels including waste incineration for vessels coming from overseas.	• No direct activities but some marina health trials and willingness to be more engaged • Proximity to mangroves and use of waterways

Stakeholder	association	existing activities within mangrove communities
		• Education and awareness
NSW District Anglers Association	The NSW District Anglers Association is a recreational fishing network, providing resources and some support to members. The NSW District Anglers Association organises local fishing competitions and partners with other groups to coordinate state and national fishing competitions.	• Recreational fishing, fishing competition
Newcastle University Student Environment Club (NUSEC)	Organises and partners with other organisations to run environmental campaigns, clean-ups and revegetation projects.	• Beach clean-ups
NSW DPI	NSW DPI regulates fishing in NSW, including license issuing and catch regulations. The NSW DPI is responsible for issuing mangrove clearing permits. Lead agency for aquatic, environmental and agricultural biosecurity.	• Engagement with risk creators around specific biosecurity threats • Organises biannual meetings with private port operators, environment and community stakeholders • Community education of marine biosecurity threats • Monitoring of aquatic threats
Operation Posidonia	Operation Posidonia is a program to replant and restore seagrass meadows. Operation Posidonia coordinates volunteers to collect seagrass fragments that wash ashore after storms and anchor damage so that the seagrass fragments can be replanted.	• Collection point in Newcastle with volunteers who facilitate replanting
Port Authority of NSW	State-owned company responsible for facilitating safe navigation and operations for the ports of Sydney Harbour, Port Botany, Newcastle Harbour, Port Kembla, Eden and Yamba. The Port Authority of NSW has the ability to impact shipping practice and communicate important information to incoming vessels.	• No direct activities
Port of Newcastle	The Port of Newcastle is a private company which operates Newcastle Port, managing services and trade. The Port of Newcastle has relevance because of relationships with risk creators and as a point of intervention for risk. Newcastle Port have a biosecurity response plan, biosecurity incursion kits and a good relationship with biosecurity staff who are constantly on port grounds performing inspections. Port of Newcastle staff sit on the NSW Marine Pest Advisory Group and Newcastle Port Users Group.	• Some limited mangrove stands on port land • Saltmarsh land area mapping undertaken for the last 4 years • Staff trained in biosecurity threats and response (though mainly aquatic and human health risks)

Stakeholder	association	existing activities within mangrove communities
Professional Fisherman's Association	Representative voice and leadership for the fishing industry. The Professional Fisherman's Association engages in advocacy and research to benefit industry.	• Fishing and boating activities in mangrove ecosystems
Recreational Fishing Alliance of NSW (Australian National Sports Fishing Association)	The Recreational Fishing Alliance of NSW is the peak representative body for recreational fishers. The Recreational Fishing Alliance of NSW communicate with government and advocates for sustainable fisheries access for recreational use. The alliance produces educational resources and uses efficient communication channels to issue alerts for dangerous conditions etc. A priority identified by the Recreational Fishing Alliance of NSW is to encourage government to invest in the protection and improvement of vital fish and marine habitats and in activities to improve water quality. The Recreational Fishing Alliance of NSW also provides insurance for recreational fishers and organises competitions.	• Organise fishing competitions • Communication with fishers within mangrove ecosystems
Sandy Bottom Boat Charters	Fishing and cruising boat groups.	• River boat cruises • Previous work with research teams undertaking water quality sampling and ecosystem health surveys
The City of Newcastle Landcare groups	There are 22 local Landcare groups in the City of Newcastle region. Many focus on local revegetation and clean-up projects as well as work on bigger projects with local and national conservation organisations.	• Clean-ups in mangrove ecosystems • Campaigns to prevent the clearing of mangrove ecosystems for urban development
The Wilderness Society (Newcastle)	The Wilderness Society is a national community-based environment protection organisation. Local Wilderness Society campaigns choose the issues specific to them. In Newcastle, the group focus on coal seam gas and the Places You Love Initiative, which is a campaign to strengthen Australia's laws for the protection of the environment.	• No direct activities • Support other local community groups in wetlands activities and clean-ups
University of Newcastle School of Environmental and Life Sciences	Environmental conservation and coastal and marine science research.	• Research projects and rehabilitation work in intertidal areas including on-going research trials at Kooragang Wetlands and mangrove communities around Australia • Collaboration with local groups such as the Hunter Wetlands Centre to assist with pest and species

Stakeholder	association	existing activities within mangrove communities
		identification and sample analysis

Other mangrove stakeholders

Table 6: *List of some of the relevant national stakeholders and existing relevant activities associated with mangrove communities.*

Stakeholder	Who are they?	Association with mangroves
Australian Mangrove and Saltmarsh Network	Network of researchers involved in mangrove and saltmarsh related research. Facilitates improved communication and showcasing of research results to relevant stakeholders.	• Linked-in research teams and students regularly spend time in mangrove communities undertaking research trials • Annual conference including field-day visits to mangrove and saltmarsh ecosystems
Australian Marine Conservation Society	The Australian Marine Conservation Society is a charity organisation which undertakes research and advocacy to support improved management decisions from environmental conservation. Previous work includes extensive surveys in mangrove and tidal habitats which helped contribute to government and industry recognition of mangroves as critical fish nursery areas. Other activities have included field studies to protect wetlands including Kakadu National Park, the Boondall Wetlands Reserve, Calley and Towra Point wetlands and the publication of 'Field Manual for Tidal Swamps.'	• Field surveys and volunteer network operating within mangrove ecosystems
BirdLife Australia	BirdLife Australia is a not-for-profit bird conservation organisation. BirdLife Australia works on advocacy, science and conservation projects for the protection of birds in Australia. BirdLife Australia relies heavily on passionate volunteers to undertake much of its project work.	• Migratory Shorebirds Project – conducts shorebird monitoring and undertakes projects to advocate for conservation of critical shorebird habitat, including mangrove communities • The Australian Wader Study Group is a special interest group of BirdLife Australia and conducts surveys and leg tagging of shorebirds
Blue Carbon Lab	The Blue Carbon lab is an Australian-based research group which investigates wetland decomposition, CO_2 emissions, carbon sequestration and microbial activity. Other projects include reef and seagrass restorations, ecosystem services and marine biosecurity case studies.	• Research field visits in coastal wetlands and mangrove ecosystems in various countries • Developed the Australian Marine Biosecurity Database to centralise published reports of marine pests around

Stakeholder	Who are they?	Association with mangroves
		Australia[16]
Environment and Invasives Committee	The Environment and Invasives Committee provides national policy leadership on the identification, prevention and management of invasive plant, vertebrate and invertebrate species that adversely impact the environment, economy and community.	• No direct activities
Fisheries Research and Development Corporation	Funds research, development and extension activities for the benefit of Australian fisheries and aquaculture businesses. The Fisheries Research and Development Corporation is relevant for its potential interest in supporting activities to protect mangrove communities for fisheries sustainability.	• No direct activities • Funds some activities in mangrove ecosystems concerning habitat change and intertidal bivalve species
International Society for Mangrove Ecosystems	Non-government organisation working to support research into mangrove health and projects to protect and restore mangrove habitat to support livelihoods around the world. Relevant for its links to groups with first-hand experience with mangrove ecosystems in countries outside of Australia.	• Current projects include support for rehabilitation and plantings of mangroves in Sabah (Malaysia), Gujarat (India) and Tarawa (Kirribati), training courses in mangrove health and rehabilitation and school tours of mangrove ecosystems in Japan • The Tropical Coastal Ecosystems Portal (TroCEP) facilitates the sharing of information on current issues relating to tropical coastal ecosystems, starting with mangrove ecosystems • Hosts the Global Mangrove Information system database which makes available information on mangroves from around the world
Invasive Species Council	The Invasive Species Council engages in advocacy, research and support of projects to prevent and minimise the effects of invasive species on the natural environment.	• No direct activities
Mangrove Action Project	The Mangrove Action Project is a non-profit organisation which uses a collaborative approach to educate and promote the importance of preserving mangrove ecosystems and the use of innovative solutions to restore them.	• Demonstration sites across Asia promote the benefits of rehabilitating abandoned shrimp ponds back to mangrove swamp • Community support for rehabilitating abandoned shrimp

[16] http://ausmarinepathogendatabase.com/database/

Stakeholder	Who are they?	Association with mangroves
		ponds
MangroveWatch (TropWATER)	MangroveWatch is a program based out of the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) which provides support, equipment and training to local groups for mangrove health monitoring activities. Local groups source their own funding for activities and may sub-contract MangroveWatch to analyse their data.	• MangroveWatch (through Earthwatch) has formed a partnership with the Coca-Cola Australia Foundation and the Carpentaria Land Council Rangers to address marine debris and pollution issues in the lower Gulf • The MangroveWatch research team (TropWATER) conducts aerial surveys of the coastline and produces the Shoreview resource to provide a virtual record of mangrove health and potential issues. The Shoreview tool has been designed so that local MangroveWatch groups or others can also contribute images to the database
Marine Pest Sectoral Committee	The Marine Pest Sectoral Committee develops and coordinates the implementation of harmonised, national arrangements to identify, minimise and address the pest risk to Australia's marine environment and associated industries, and plays an advocacy role within Government for highlighting the impact of marine pests on Australia's marine environment and associated industry.	• No direct activities
Maritime Industry Australia Limited	Maritime Industry Australia Limited represent the interests of maritime businesses such as international trading ships, cargo ships, and vessels that service oil and gas rigs. Maritime Industry Australia Limited are relevant because they can push information to their partners who are risk creators. Maritime Industry Australia Limited are involved in reviewing international guidelines for biofouling and are involved in environmental sustainability working group for ports.	• No direct activities
National Environmental Science Program (NESP)	Developed under the former Department of Environment and Energy the NESP program now sits within DAWE. The NESP invests in a range of science projects related to environmental protection and includes a number of relevant research hubs including: - Marine Biodiversity Hub	• Funds MangroveWatch aerial surveys

Stakeholder	Who are they?	Association with mangroves
	- Northern Australia Environmental Resources Hub - Tropical Water Quality Hub - Earth Systems and Climate Change Hub	
OceanWatch Australia	OceanWatch Australia works with industry and the community to implement and support activities that encourage sustainable use of marine resources and that support the health and productivity of marine ecosystems.	• Organises volunteer groups e.g. coastal walkabout • Training for fisherman • Marine biosecurity awareness material project which included the Educational Resources Database[17]
Seafood Industry Australia	Peak body representing the Australian seafood industry. Some activities towards aquatic biosecurity.	• No direct activities
Seagrass-Watch	Seagrass-Watch is an Australian network, which supports local assessment and monitoring of seagrass ecosystems and now operates in 26 countries around the world. Local Seagrass-Watch groups can upload and share data to support improved decision-making and conservation on a larger scale. Seagrass-Watch provides educational support, guides and manuals and uses data to support larger research projects.	• Monitoring for seagrass density, species composition, algal cover, canopy height, sediment habitat and changes overtime • Groups established in almost 30 locations around Australia, including Cairns
Tangaroa Blue	Tangaroa Blue is an Australian organisation which works to remove debris and rubbish from the ocean and to reduce plastic waste at its source. Tangaroa Blue partners with a wide range of local community organisations to conduct beach and river clean-ups and established the Australian Marine Debris Database to log data and analyse trends in ocean rubbish.	• Clean-up initiatives with local community groups and in remote locations along the north coast of Australia undertaken within and around mangrove communities
Wildlife Queensland Coastal Citizen Science	Management and training of volunteers to contribute to the management of mangroves and seagrass ecosystems around Brisbane.	• MangroveWatch activities in the Logan River • Mangrove monitoring along Bulimba Creek, Brisbane River • Curlew survey activities

[17] See https://www.oceanwatch.org.au/marine-pests-biosecurity/

Cairns stakeholder capacity and capability matrix

Table 7: *Cairns mangrove community stakeholder characteristics relevant to biosecurity activities, as assessed by Plant Health Australia*

Stakeholder	Impact on stakeholder		Governance			Incursion capacity				Preparedness capacity					Engagement and communication needs	
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities?	Are they signatory to a response deed?	Has a mechanism to make collective decisions?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
GOVERNMENT STAKEHOLDERS																
Biosecurity Queensland	Some through marine biosecurity team	HIGH	Yes through QLD government, to both the EPPRD and NEBRA	Yes	State	In-kind and financially	Yes	Planning, stakeholder liaison, surveillance, diagnostics, incursion management, would be lead agency for a response in Qld	Yes through online platforms and community meetings if needed	Yes	Yes	Yes	Yes	Yes	HIGH	Direct consultation
Northern Australia Quarantine Strategy	Limited- potential for some ad hoc, general survey	MEDIUM	Yes as part of DAWE to both the EPPRD and NEBRA	Yes as part of DAWE	Northern Australia, International	Yes	Limited	Entomologists, pathologists, botanists, surveillance	Yes	Yes	Yes	Yes	Yes	Yes	HIGH	Direct consultation
Cairns Port (Ports North)	Close proximity of mangroves to port activities, manage mangroves through their port management plan	LOW	No from a practical perspective but yes as a QLD Government entity	Yes	Regional	Some in-kind around ports	Yes- short-term	Surveillance, could provide mangrove and seagrass mapping data	Limited	Yes	Could identify marine pests. Would not be able to identify plant pests	Yes	Limited	Limited	MEDIUM	Direct communication

Stakeholder	Impact on stakeholder		Governance			Incursion capacity				Preparedness capacity					Engagement and communication needs	
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities ?	Are they signatory to a response deed?	Has a mechanism to make collective decisions ?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
Cairns Regional Council	Issue permits for mangrove removal. Manage public land with mangroves on them. Manage boat ramps.	LOW	No	Yes	Operates locally with regional collaboration	Limited	Yes	Surveillance, sampling community liaison and coordination	Yes	Yes if there was capacity	Could identify a problem	Yes	Limited	Yes if funding structure could support staffing	MEDIUM	Direct consultation
Qld Department of Environment and Science	Research projects, national parks	LOW	Yes through Queensland government to NEBRA and EPPRD	Yes	Queensland	Very limited	Limited	Plant health specialists, sampling	Yes	Yes	Could identify a problem	Yes	No	Limited	LOW (outside of national parks)	Direct consultation
Wet Tropics Management Authority	Manges land management activities within Wet Tropics region	MEDIUM (if within Wet Tropics region)	No	Yes	Regional	Some in-kind if within Wet Tropics area	Some if within Wet Tropics area	Sampling, community and group coordination	Yes	Could encourage groups undertaking land management activities on the ground	n/a	Yes	Some- if within Wet Tropics area	Yes	HIGH if within Wet Tropics area	Direct consultation
INDIGENOUS STAKEHOLDERS																
Indigenous ranger groups (these are a subset of the Traditional Owners and undertake a range of activities on behalf of the community)	Surveillance activities and cultural life within mangrove community environments	HIGH	No	Yes	Individual groups local scale. Ranger program national	Limited in-kind	Yes	Sampling, surveillance, community engagement, assist with access to indigenous lands	Yes- within communities	Yes	Yes	Yes	Limited but eager to assist	Yes	HIGH	Direct consultation

Stakeholder	Impact on stakeholder		Governance			Incursion capacity				Preparedness capacity					Engagement and communication needs	
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities?	Are they signatory to a response deed?	Has a mechanism to make collective decisions?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
Traditional Owners (includes all indigenous community members)	Cultural, daily interaction	HIGH	No	Yes- within communities	Local	Some in-kind	Yes	Surveillance and sampling (with training)	Yes- within an affected community	Yes	Yes – could identify something different	No – but likely will contact someone who does	Some	Some	HIGH	Direct consultation with relevant decision-making committees within affected community and direct communication with the rest of the community
RESEARCH STAKEHOLDERS																
Australian Institute of Marine Science (Townsville)	Funding research projects	LOW	No	Yes	National Regional	Some advisory assistance	No	Technical advice	Yes	No	n/a	No	No	Potentially	LOW	Indirect information flow
Australian Tropical Herbarium	Research activities	LOW	No	Yes	Regional National as part of the combined Australian herbarium network	Technical advice in-kind	No	n/a	Yes	No	Could identify a problem	Yes	No	Yes	HIGH	Direct communication
Great Barrier Reef Foundation	Research activities	LOW depending on how the flow-on effects to the reef	No	Yes	Regional	No	No	n/a	Yes	Potentially seagrass related activities	n/a	No	No	No	LOW	Indirect information flow
TropWATER (JCU)	Research and surveys within mangrove community ecosystems	MEDIUM	No	Yes	Regional National International	Technical advice in-kind	Yes	Plant health expertise, local knowledge, networks, community engagement, surveillance	Yes	Yes	Could identify a problem	No	Limited	Yes	HIGH	Direct consultation

Stakeholder	Impact on stakeholder		Governance			Incursion capacity				Preparedness capacity					Engagement and communication needs	
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities?	Are they signatory to a response deed?	Has a mechanism to make collective decisions?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
ENVIRONMENTAL AND COMMUNITY STAKEHOLDERS																
Cairns Far North Environment Centre	Clean-ups and MangroveWatch activities	HIGH	No	No	Local	Some in-kind	Volunteers	Surveillance, boots on ground	Yes- locally	Yes- MangroveWatch activities	Unlikely without training	No	Limited	Yes	HIGH (pending funding)	Direct information flow
Cairns Botanic Gardens	Mangroves within the gardens	MEDIUM	No	Yes	Local	No	Yes	Sampling, plant health knowledge	Yes	Yes within the garden	Could identify a problem	Yes	Limited	Yes	MEDIUM (within the garden)	Direct information flow
Cairns Local Marine Advisory Panel	Environmental advocacy	MEDIUM	No	No	Local	No	No	n/a	Yes through personal networks	No	No	No	No	No	MEDIUM	Direct information flow
Great Barrier Reef Legacy	MangroveWatch activities, research projects	MEDIUM	No	Yes	Local	Some in-kind	Yes	Sampling, surveillance, community engagement	Yes	Yes – MangroveWatch	Could potentially identify a problem	No	No	Yes	MEDIUM	Indirect information flow
Holloways Beach Environmental Education Centre	School education activities within mangrove communities	LOW	No	Yes	Local	No	No	n/a	No	Yes if staff are aware of pests to look out for	Might identify a problem	No	No	Yes- could include biosecurity awareness in education program	MEDIUM	Indirect information flow
James Cook University- TropEco Sustainability Club	Environmental campaigns	LOW	No	No	Local	In-kind	Yes	Sampling, surveillance	Yes	No	Might identify a problem	No	Limited	Limited	LOW	Indirect information flow
Mulgrave Landcare and Catchment	Land management activities	LOW	No	Yes	Local	In-kind	Yes	Sampling, boots on ground	Yes through personal networks and social media	Yes	Unlikely	No	No	Yes if relevant to their activities	MEDIUM	Indirect information flow
MangroveWatch (Cairns)	Mangrove health monitoring	HIGH	No	No	Local	In-kind	Yes	Sampling, boots on ground	Yes	Yes	Could identify a problem	No	Some	Yes	HIGH	Direct consultation

Stakeholder	Impact on stakeholder		Governance			Incursion capacity				Preparedness capacity					Engagement and communication needs	
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities ?	Are they signatory to a response deed?	Has a mechanism to make collective decisions ?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
Marine Teachers Association of QLD	Marine health school curriculum and field trips	LOW	No	Yes	State	No	No	n/a	Yes	No	n/a	Dependant on individual	Some	Some	MEDIUM	Indirect information flow
Reef Citizen Science Alliance	Marine health activities	LOW	No	No	Regional	Volunteers	Yes	Sampling, boots on ground	Yes	Limited	Could identify a problem	Dependant on individual	No	Yes	MEDIUM	Indirect information flow
Reef Restoration Foundation	No	MEDIUM- dependant on flow-on effects to the reef	No	Yes	Regional	No	No	n/a	Yes	No	No	No	No	Yes	LOW	Indirect information flow
Terrain NRM	Land management activities	MEDIUM- if within managed area	No	Yes	Regional	No	Yes	Sampling, surveillance, community engagement	Yes	Yes	Could identify a problem	Yes	No	Yes	MEDIUM	Direct consultation (if incursion is within or adjacent to managed area)
INDUSTRY ORGANISATIONS AND BUSINESSES																
Adventure North Australia	Tour group activities	LOW	No	Yes	Regional	No	No	n/a	No	Yes	No	No	No	No	LOW	Indirect information flow
Asia- Pacific Superyacht Association (APSA)	Promotes and represents superyacht industry	LOW	No	Yes	International	No	No	n/a	Yes	No	n/a	Probably	No	No	LOW	Indirect information flow
Australian Superyacht Services	Superyacht services	LOW	No	Yes	Regional	No	No	n/a	Yes	No	n/a	Yes	No	Maybe	MEDIUM	Direct communication
Cairns Adventure Group	Tour group boat activities	LOW	No	Yes	Regional	No	No	n/a	No	Could keep a look out for unusual pest symptoms	May identify a problem	No	No	No	LOW	Indirect information flow
Cairns Reef Fishing	Fishing	LOW	No	Yes	Local	No	No	n/a	No	Yes	No	No	No	Maybe	LOW	Direct communication

Stakeholder	Impact on stakeholder		Governance			Incursion capacity				Preparedness capacity					Engagement and communication needs	
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities ?	Are they signatory to a response deed?	Has a mechanism to make collective decisions ?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
Cape York Tours	Tour group activities	LOW	No	Yes	Regional	No	No	n/a	No	Yes	No	No	No	No	LOW	Indirect information flow
Carter Marine Services	Superyacht services	LOW	No	Yes	Local	No	No	n/a	Yes	No	n/a	Yes	No	No	MEDIUM	Direct communication
Coral expeditions	Cruise liner operator	LOW	No	Yes	Regional National International	No	No	n/a	No	No	n/a	Yes	Some	Some	MEDIUM	Direct communication – could communicate risk and expectations to passengers
Great Barrier Reef Sport Fishing Charters	Fishing	LOW	No	Yes	Local	No	No	n/a	Limited	Yes	No	No	No	Yes	LOW	Direct communication
Melanesian Yacht Services	Superyacht services	LOW	No	Yes	Local	No	No	n/a	Yes	No	n/a	Yes	No	No	MEDIUM	Direct communication
Superyacht Group (Great Barrier Reef)	Superyacht services	LOW	No	Yes	Local Regional	No	No	n/a	Yes	No	n/a	Yes	No	No	MEDIUM	Direct communication
Superyacht Logistics	Superyacht services	LOW	No	Yes	Local	No	No	n/a	Yes	No	n/a	Yes	No	No	MEDIUM	Direct communication
Superyacht Training and Recruitment	Superyacht staff training	LOW	No	Yes	Local	No	No	n/a	Limited	No	n/a	Yes	Could include biosecurity considerations into superyacht staff training	Limited	LOW	Indirect information flow
Tourism Tropical North Queensland	Promotes Queensland tourist sites	LOW- depending on flow-on effects to the reef	No	Yes	Regional National International	No	No	n/a	Yes	No	n/a	No	No	No	LOW	Indirect information flow

Newcastle stakeholder capacity and capability matrix

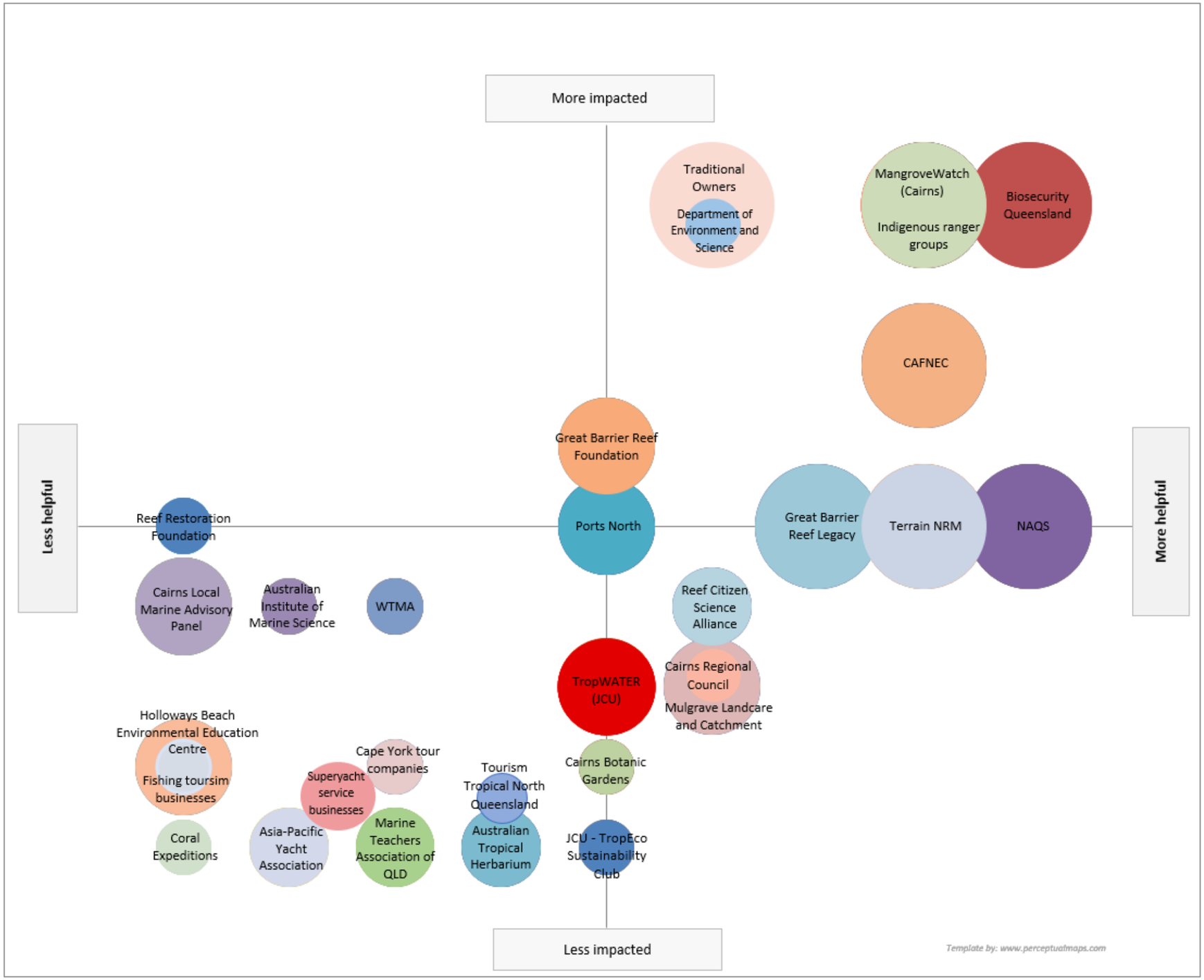

Figure 8: *Newcastle mangrove community stakeholder characteristics relevant to biosecurity activities, as assessed by Plant Health Australia.*

Stakeholder	Impact on stakeholder	Governance		Incursion capacity				Preparedness capacity					Engagement and communication needs			
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities?	Are they signatory to a response deed?	Has a mechanism to make collective decisions?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
GOVERNMENT STAKEHOLDERS																
City of Newcastle Council	Issue permits for mangrove removal. Manage public land with mangroves on them. Manage boat ramps.	LOW - MEDIUM	No	Yes	Operates locally with regional collaboration	No	No	Surveillance, sampling community liaison and coordination	Yes	No	Could identify a problem	Yes	No	Yes if funding structure could support staffing	LOW	Direct consultation
NSW Department of Planning, Industry and Environment	Research projects, national parks	LOW	Yes through NSW government, to both the EPPRD and NEBRA	Yes	State	Very limited	Limited	Plant health specialists, sampling	Yes	Yes	Could identify a problem	Yes	No	Limited	LOW (outside of national parks)	Direct consultation
Hunter Local Land Services	Wetland management activities	HIGH	Yes through NSW government	Yes	Regional	Yes	Yes	Surveillance, plant health specialists, community engagement	Yes	Yes	Yes	Yes	Some	Yes	HIGH	Direct consultation
NSW Department of Primary Industries (DPI)	Some through marine biosecurity team	HIGH	Yes through NSW government for the EPPRD and NEBRA	Yes	State	Yes	Yes	Planning, stakeholder liaison, surveillance, diagnostics, incursion management, would be lead agency for a response in NSW	Yes through online platforms and community meetings if needed	Yes	Yes	Yes	Limited	Yes	HIGH	Direct consultation
Port Authority of NSW	No direct activities	LOW	No	Yes	State	No	No	n/a	Yes	No	Could identify marine pests. Could not identify plant pests.	Yes	Some	Some	MEDIUM	Direct communication

Stakeholder	Impact on stakeholder	Governance		Incursion capacity				Preparedness capacity					Engagement and communication needs			
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities?	Are they signatory to a response deed?	Has a mechanism to make collective decisions?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
INDIGENOUS STAKEHOLDERS																
Awabakal Local Aboriginal Land Council	Cultural and land management	HIGH	No	Yes	Local	No	No	n/a	Yes	No	No	No	No	No	HIGH	Direct consultation
Traditional Owners	Cultural, daily interaction	HIGH	No	Yes- within communities	Local	Some in-kind	Volunteers	Surveillance and sampling (with training)	Yes- within an affected community	Yes	Yes – could identify something different	No – but likely will contact someone who does	Some	Some	HIGH	Direct consultation
RESEARCH STAKEHOLDERS																
University of Newcastle School of environmental and life sciences	Research projects and health monitoring of mangrove communities	MEDIUM	No	Yes	Local Regional National International	In-kind advisory role	Limited	Diagnostics, sampling, RD&E capacity if required	Yes	Yes	Could identify a problem	Dependant on research team	No	Yes	MEDIUM	Direct consultation
ENVIRONMENTAL AND COMMUNITY STAKEHOLDERS																
Conservation volunteers Australia (Newcastle)	No direct activities within mangrove communities	LOW	No	Yes	Local National	Volunteers	Yes	Sampling, boots on ground	Yes	No	No	No	No	Yes	MEDIUM	Indirect information flow
Hunter Bird Observers Club	Bird watching and some land management participation	MEDIUM	No	Yes	Local	Volunteers	Yes	Boots on ground, sampling	Yes	Yes	Could identify a problem	No	No	No	LOW	Indirect information flow
Hunter Community Environment Centre	Land management responsibility of mangrove community area	HIGH	No	Yes	Local	Volunteers	Yes	Sampling, boots on ground, community engagement, volunteer coordination	Yes	Yes	Could identify a problem	No	Limited	Yes	HIGH	Direct consultation

Stakeholder	Impact on stakeholder	Governance		Incursion capacity				Preparedness capacity				Engagement and communication needs			
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities?	Are they signatory to a response deed?	Has a mechanism to make collective decisions?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
Kooragang Landcare Volunteers	Land management activities within mangrove community areas	HIGH	No	No	Local	Volunteers	Yes	Sampling, boots on the ground	Yes	Yes	Could identify a problem	Yes	Limited	Limited	MEDIUM	Indirect information flow
Kooragang Wetlands Rehabilitation Project	Land management activities within mangrove community areas	HIGH	No	Yes	Local	Yes- if within Kooragang Wetlands	Yes	Sampling, boots on ground	Yes	Yes	Could identify a problem	Yes	Limited	Yes	MEDIUM	Direct communication
Marine Parks Association	Advocacy and activities to support marine environment	LOW	No	Yes	Local	No	No	n/a	Yes	Yes	Might identify a problem	No	No	Yes	MEDIUM	Indirect information flow
Nature Conservation Council of NSW	Environmental advocacy	MEDIUM	No	Yes	State	Could mobilise volunteers	Limited	Volunteer coordination	Yes	No	Could identify a problem	No	No	Potentially	MEDIUM	Indirect information flow
Newcastle Community Consultative Committee on the Environment (CCCE)	Local community representation of environmental concerns	MEDIUM	No	No	Local	No	No	n/a	Yes- through personal networks	No	No	No	No	No	MEDIUM	Direct communication
NSW District Anglers Association	Fishing	MEDIUM	No	Yes	State	Limited	No	n/a	Yes	Yes- could encourage anglers to participate in general surveillance	Might identify a problem	No	Happy to receive awareness materials	No	MEDIUM	Direct communication
Newcastle University Student Environment Club (NUSEC)	Environmental activities and campaigns	LOW	No	No	Local	In-kind	Volunteers	Boots on the ground	Yes	No	Might identify a problem	No	No	No	LOW	Indirect information flow

Stakeholder	Impact on stakeholder	Governance		Incursion capacity				Preparedness capacity					Engagement and communication needs		
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities?	Are they signatory to a response deed?	Has a mechanism to make collective decisions?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
Operation Posidonia	Seagrass re-planting	HIGH (if affecting seagrass)	No	Yes	Local Regional National	In-kind	Volunteers	Coordinate volunteers	Yes	Yes	Might identify a problem	No	No	Potentially	MEDIUM	Indirect information flow
Recreational Fishing Alliance of NSW (Australian National Sports Fishing Association)	Fishing	MEDIUM	No	Yes	State	No	No	No	Yes	Yes	No	No	No	No	LOW	Indirect information flow
The City of Newcastle Landcare groups	Land management activities	LOW	No	No	Local	Potentially	Volunteers	Sampling, boots on the ground	Yes	Yes	Could identify a problem	Dependent on individual	Limited	Limited	LOW	Indirect information flow
The Wilderness Society (Newcastle)	Environment campaigns and activities	LOW	No	Yes	Local Regional National	No	No	n/a	Yes	No	No	No	No	No	MEDIUM	Indirect information flow
INDUSTRY ORGANISATIONS AND BUSINESSES																
B and L Fishing and Cruises	Fishing tourism	MEDIUM-depending on impact to fish populations	No	Yes	Local	No	No	n/a	Limited	Yes	No	No	No	No	LOW	Indirect information flow
Commercial Fisherman's Cooperative	No direct activities	MEDIUM-dependent on impact to fish populations	No	Yes	Local	No	No	n/a	No	No	n/a	No	No	No	LOW	Indirect information flow
Hunter Cargo and Customs	No direct activities	LOW	No	Yes	Local International	No	No	n/a	No	No	n/a	No	No	No	LOW	Indirect information flow
Newcastle Coal Infrastructure Group	Port operations	LOW	No	Yes	Local	Yes if on or adjacent to port land	Yes	Boots on ground, surveillance	No	No	No	Yes	No	Potentially if there is risk to their business	LOW	Direct communication

Stakeholder	Impact on stakeholder	Governance			Incursion capacity				Preparedness capacity				Engagement and communication needs			
	Interaction with mangrove communities	Impact on stakeholder from a biosecurity incident within mangrove communities?	Are they signatory to a response deed?	Has a mechanism to make collective decisions?	What scale does the stakeholder operate within?	Willing to contribute in-kind or financially to a response?	Could contribute staff resources to a response?	What skills could they contribute to a response? e.g. Sampling, diagnostics?	Could contribute via awareness and information flow?	Could build general surveillance into existing activities?	Understanding of pests and diseases/ could identify a problem?	Is aware of what to do if something unusual is spotted?	Have capacity or interest to contribute to preparedness activities without funding?	Have capacity or interest to contribute to preparedness activities with funding?	Willingness to engage with biosecurity activities	Suggested communication approach during a plant pest incursion affecting mangrove communities
Newcastle Cruising Yacht Club	Marina operations	LOW	No	Yes	Local	Some in-kind	Limited	Boots on ground	Yes	Yes	Could identify a problem	No	Limited	Limited	HIGH	Direct communication
Port of Newcastle	Close proximity of mangroves to port activities	LOW	No	Yes	Local	Some in-kind around ports	Yes-short-term	Boots on ground	Yes	Yes	Could identify marine pest problem. Probably would not identify plant pest	Yes	Limited	Yes	HIGH	Direct communication
Sandy Bottom Boat Charters	Fishing and boat hire	LOW-MEDIUM	No	Yes	Local	No	No	Boat hire	No	Yes	No	No	No	No	LOW	Indirect information flow

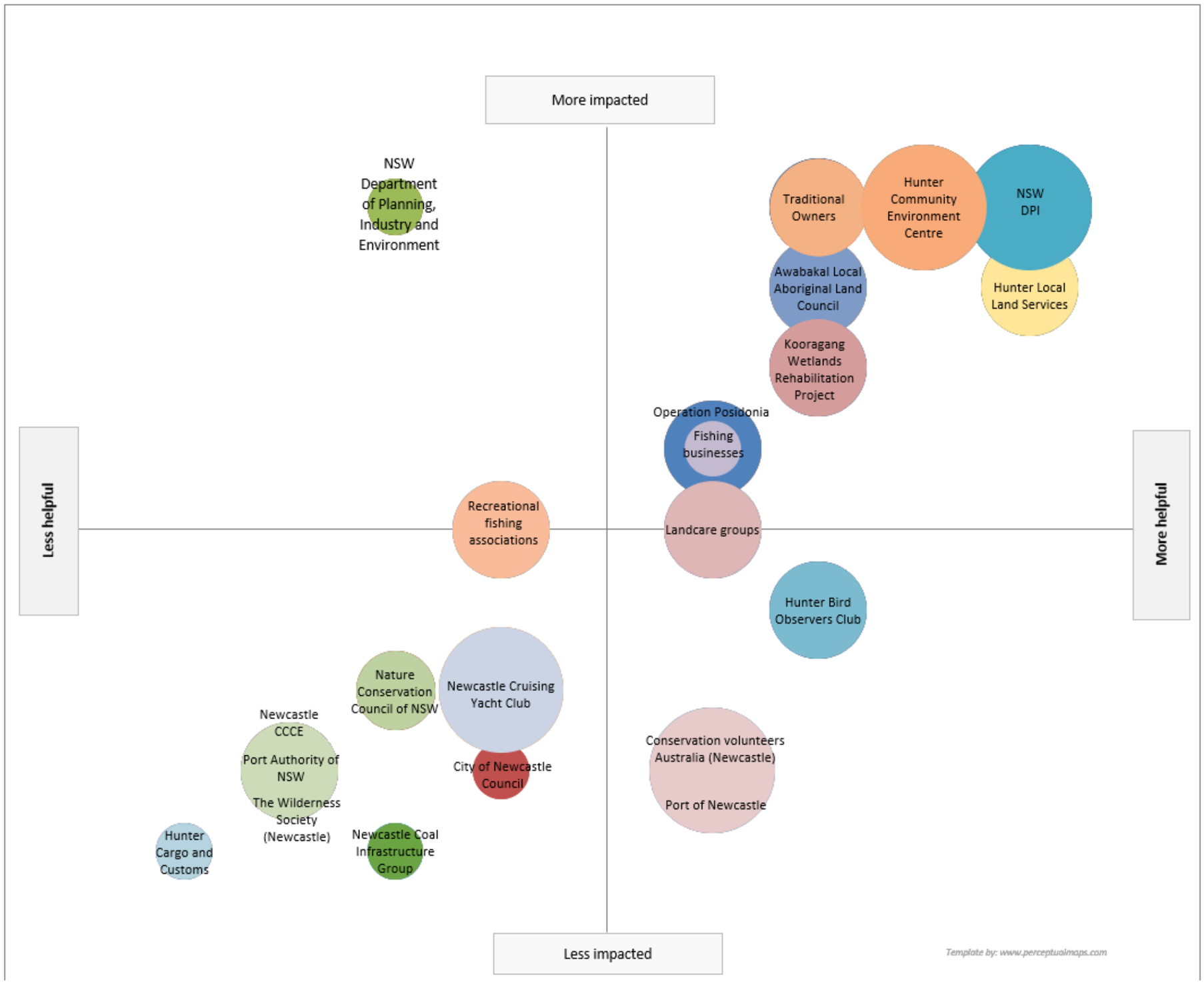

Figure 9: *Assessment of Newcastle mangrove community stakeholder groups in terms of impact and helpfulness during an emergency plant pest response affecting mangrove communities that are relevant to the stakeholder.*
**Size of circle indicates engagement interest. Colour has no relevance.*

References

Burns C and Davey G (2010). Exploring our oceans – saltmarsh. Marine Education Society of Australasia. http://www.mesa.edu.au/seaweek2010/saltmarsh.asp [accessed April 2020].

City of Newcastle Council (2019). Environment. https://www.newcastle.nsw.gov.au/Living/Environment/Stormwater [accessed May 2020].

Dawul Wuru Aboriginal Corporation (2014). Yirriganydji kulpul-wu mamingal – looking after Yirrganygi sea country, Bungalow, Queensland.

Deloitte Access Economics (2017). At what price? The economic, social and icon value of the Great Barrier Reef, Brisbane, Queensland.

Douglas N, Ellis B and Frost T (2018). The demand and economic, environmental and social impacts of Australian cruise tourism. Australasian Transport Research Forum 2018 Proceedings 30 October to 1 November 2018, Darwin, Australia.

Goudkamp K and Chin A (2006). Mangroves and saltmarshes, the state of the Great Barrier Reef on-line. Great Barrier Reef Marine Park Authority, Townsville. http://www.gbrmpa.gov.au/publications/sort/mangroves_saltmarshes [accessed October 2019].

Herbert C (2007). Mangrove proliferation and saltmarsh loss in the Hunter Estuary. *The Whistler,* 1(2007): 38-45.

Hunter Local Land Services (2016). Kooragang Wetland rehabilitation project: 21 years of ecosystem repair and management in the Hunter River Estuary. https://kooragangwetlands.files.wordpress.com/2014/10/2016-03-8-kwrp-grn-report.pdf [accessed November 2019].

James Cook University (2016). Citizen scientist discovers rare mangrove species. https://www.jcu.edu.au/news/releases/2016/april/citizen-scientist-discovers-rare-mangrove-species [accessed August 2020]

Ports North (2020). Cruise liner schedule – 2018 – Cairns seaport. https://s3-ap-southeast-2.amazonaws.com/os-data-2/portsnorth-com-au/listingforms/page267/cruise_schedule_-_2018.pdf [accessed October 2019].

Port of Newcastle (2019). Port of Newcastle supports Hunter Region's construction and industrial growth. Port of Newcastle news and media, January 25. https://www.portofnewcastle.com.au/news/port-of-newcastle-supports-hunter-regions-construction-and-industrial-growth/ [accessed March 2020].

Reason CL and Rasheed MA (2018). Seagrass habitat of Cairns Harbour and Trinity Inlet: annual monitoring report 2017. James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research Publication 18/09, Cairns.

Tourism Research Australia (2013). Newcastle and visitor profile satisfaction report – summary of results. Australian government, Sydney, Australia.

Tourism Research Australia (2018). Local government area profiles, Cairns, Queensland 2018. Austrade, Tourism Research Australia. https://www.tra.gov.au/Regional/Local-Government-Area-Profiles/local-government-area-profiles [accessed May 2020].

APPENDIX 4

Additional references

NOTE: *These references were used as background resources to assist with understanding of the mangrove ecosystem. They have not been cited specifically in the document but are considered useful resources and are included in this appendix for information.*

Aston P (2009). Chrysomelidae of Hong Kong Part 3 subfamily Galerucinae. *Hong Kong Entomological Bulletin*, 1(2), Nov 2009.

Atkinson T and Peck S (1994). Bark and Ambrosia Beetles of South Florida 313. Annotated checklist of the bark and ambrosia beetles (Coleoptera: Platypodidae and Scolytidae) of tropical southern Florida, 77: 312-329.

Bahder B, Halbert S, Mou D, Helmick E, Soto N, Otero M and Segarra A (2018). Establishment of the sea grape flatid, *Petrusa epilepsies* (Hemiptera: Fulgoroidea: Flatidae), in Florida. *Florida Entomologist*, 101(4): 634-641. https://doi.org/10.1653/024.101.0427

CABI (2019a). *Orgyia postica* (cocoa tussock moth). Invasive species compendium https://www.cabi.org/isc/datasheet/37808

CABI (2019b). *Homona coffearia* (tea tortrix). Invasive Species Compendium https://www.cabi.org/isc/datasheet/27580

CABI (2019c). *Eriocheir sinensis* (Chinese mitten crab). Invasive Species Compendium https://www.cabi.org/isc/datasheet/84120

CABI (2019d). *Charybdis japonica* (lady crab). Invasive species compendium. https://www.cabi.org/isc/datasheet/89054

CABI (2019e). *Perna viridis* (Asian green mussel) https://www.cabi.org/isc/datasheet/70090

CABI (2019f). *Mytilopsis sallei* (Caribbean false mussel). https://www.cabi.org/isc/datasheet/119604

Cognato A (2008). *Xyleborinus aemulus* (Wollaston, 1869) species page. http://xyleborini.speciesfile.org/public/site/scolytinae/home/show_taxon/2546

Conde J and Diaz H (1989). The mangrove tree crab *Aratus pisonii* in a tropical estuarine coastal lagoon. *Estuarine, Coastal and Shelf Science,* 28(6), 639-650.

Costlow J and Bookhout C (1962). The larval development of *Sesarma reticulatum* reared in the laboratory. *Crustaceana,* 4(4): 281-294.

Csoka G, Mattson W, Stone G and Price P (1998). The biology of gall inducing arthropods. General Technical Report NC – 199, Forest Service - United States Department of Agriculture, St Paul, Minnesota.

Department of Primary Industries (2019). Fishing and Aquaculture. NSW Government. https://www.dpi.nsw.gov.au/fishing/pests-diseases/marine-pests/found-overseas/seasquirt

Dineen J, Clark P, Hines A and Reed S (2001). Life history, larval description, and natural history of *Charybdis Hellerii* (Decapoda, Brachyura, Portunidae), an invasive crab in the Western Atlantic. *Journal of Crustacean Biology,* 21(3): 774-805.

Elster C, Perdomo L, Polania J and Schnetter M (1999). Control of *Avicennia germinans* recruitment and survival by *Junonia evarete* larvae in a disturbed mangrove forest in Colombia. *Journal of Tropical Ecology,* 15(6): 791-805.

Feller I (2002). The role of herbivory by wood-boring insects in mangrove ecosystems in Belize. *OKIOS,* 97(2): 167-176.

Fofonoff P, Ruiz G, Steves B, Simkanin C and Carlton J (2019). National Exotic Marine and Estuarine Species Information System. http://invasions.si.edu/nemesis/

Gara R, Sarango A and Cannon P (1990). Defoliation of an Ecuadorian mangrove forest by the bagworm, *Oiketicus kirbyi* Guidling (Lepidoptera: Psychidae). *Journal of Tropical Forest Science*, 3(2): 181-186.

Gibson-Hall E and Bilewitch J (2018). *Didemnum vexillum* the carpet sea squirt. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. https://www.marlin.ac.uk/species/detail/2231

Global Invasive Species Database (2019a). Species profile: *Eriocheir sinensis*. http://www.iucngisd.org/gisd/species.php?sc=38

Global Invasive Species Database (2019b). Species profile: *Charybdis japonica*. http://www.iucngisd.org/gisd/species.php?sc=1044

Global Invasive Species Database (2019c). Species profile: *Musculista senhousia*. http://www.iucngisd.org/gisd/species.php?sc=1031

Global Invasive Species Database (2019d). Species profile: *Perna viridis*. http://www.iucngisd.org/gisd/species.php?sc=731

Hall D (2012). Common name: puss caterpillar (larva), southern flannel moth (adult), scientific name: *Megalopyge opercularis* (J. E. Smith 1797) (Insecta: Lepidoptera: Zygaenoidea: Megalopygidae). Featured Creatures University of Florida. http://entnemdept.ufl.edu/creatures/misc/moths/puss.htm

Heppner J (1997). Urticating caterpillars in Florida: 3. Puss caterpillar and flannel moths (Lepidoptera: Megalopygidae). Florida Department of Agriculture and Consumer Services, Division of Plant Industry. Gainesville, Florida. Entomology Circular No. 381, 2.

Herborg L, O'Hara P and Therriault T (2009). Forecasting the potential distribution of the invasive tunicate *Didemnum vexillum*. *Journal of Applied Ecology*, 46: 64–72.

Ho W and Hyde D (1996). *Pterosporidium* gen.nov. to accommodate two species of Anthostomella from mangrove leaves. *Canadian Journal of Botany*, 74: 1826-1826.

Hodkinson (1992). *Telmapsylla* gen.n., an unusual psyllid from black mangrove in Florida and Costa Rica (Insecta, Homoptera, Psylloidea). *Zoologica Scripta*, July(1992): 307-309.

Lambert G (2009). Adventures of a sea squirt sleuth: unraveling the identity of *Didemnum vexillum,* a global ascidian invader. *Aquatic Invasions*, 4(1): 5-28.

Lim K, Murphy D, Morgany T, Sivasothi N and Ng P (2001). A guide to Mangroves of Singapore. The Ecosystem and Plant Diversity volume 1. Raffles Museum of Biodiversity Research, The National University of Singapore & The Singapore Science Centre. http://mangrove.nus.edu.sg/guidebooks/text/2026.htm; http://mangrove.nus.edu.sg/guidebooks/text/2018.htm

Maia R and Coutinho R (2013). The influence of mangrove structure on the spatial distribution of *Melampus coffeus* (Gastropoda: Ellobiidae) in Brazilian estuaries. *Pan-American Journal of Aquatic Sciences,* 8(1): 21-29.

Maia R, Rocha-Barreira C and Coutinho R (2012). Reproductive cycle and embryonic development of the gastropod *Melampus coffeus* (Linnaeus, 1758) (Ellobiidae) in the Brazilian Northeast. *Brazilian Journal of Biology*, 72(4): 935.

Menezes L and Peixoto A (2009). Leaf damage in a mangrove swamp at Sepetiba Bay, Rio de Janeiro, Brazil. Brazilian Journal of Botany, 32(4).

Nieves-Rivera Á, Tattar T and Williams E (2002). Sooty mould-planthopper association on leaves of the black mangrove, *Avicennia germinans* (L.) Stearn in southwestern Puerto Rico. *Arboricultural Journal*, 26: 141–155.

Offenberg J, Havanon S, Aksornkoae S, Macintosh D and Nielsen M (2006). Observations on the ecology of weaver ants (*Oecophylla smaragdina* Fabricius) in a Thai Mangrove Ecosystem and their effect on Herbivory of *Rhizophora mucronate* Lam. *Biotropica*, 36(3): 344-351.

Osorio J, Wingfield M, De Beer Z and Roux J (2015). *Pseudocercospora mapelanensis* sp. nov., associated with a fruit and leaf disease of *Barringtonia racemosa* in South Africa. *Australasian Plant Pathology,* 44(3).

Pena J (2016). Potential Invasive Pests of Agricultural Crops. CAB International, Oxfordshire, United Kingdom.

Proffitt C and Devlin D (2005). Grazing by the intertidal gastropod *Melampus coffeus* greatly increases mangrove leaf litter degradation rates. *Marine Ecology Progress Series*, 296: 209-218.

Seiple W and Salmon M (1982). Comparative social behaviour of two grapsid crabs, *Sesarma reticulatum* (Say) and *S. cinereum* (Bosc). *Journal of Experimental Marine Biology and Ecology*, 62(1): 1-24.

Shaughnessy C, Anderson E, Kasparian M, LaMontagne J and Bystriansky J (2017). Survival and osmoregulation of the purple marsh crab (*Sesarma reticulatum*) at varying salinity and Ph. *Canadian Journal of Zoology,* 95: 985-989.

Solovyeva A and Bailey K (2008). *Eriocheir sinensis*" (On-line), Animal Diversity Web. https://animaldiversity.org/accounts/Eriocheir_sinensis/

Tomascik, T and Mah A (2013). Ecology of the Indonesian seas – Part 2. Tuttle Publishing. ISBN 146290503X, 9781462905034.

Tong Y, Lee S and Morton B (2006). The herbivore assemblage, herbivory and leaf chemistry of the mangrove *Kandelia obovate* in two contrasting forests in Hong Kong. *Wetlands Ecology and Management*, 14(1) 39-52.

Wier A, Tattar T and Klekowski J (2000). Disease of red mangrove (*Rhizophora mangle*) in Southwest Puerto Rico Caused by *Cytospora rhizophorae*. *Biotropica*, 32(2): 299-306.

Williams S (2007). Introduced species in seagrass ecosystems: Status and concerns. *Journal of Experimental Marine Biology and Ecology,* 350(2007): 89-110.

Yamazaki (2016). Serious damage to mahogany by the shoot borer *Hypsipyla grandella* Zeller (Lepidoptera, Pyralidae). *Tropical Forestry*, 8: 26-34.

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