Pacific Invasive Species
Battler Series

MANAGE MARINE BIOSECURITY IN THE PACIFIC

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Our vision: A resilient Pacific environment sustaining our livelihoods and natural heritage in harmony with our cultures

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Dear Invasive Species Battler,

We are a diverse bunch of people in the Pacific region, which spans about one third of the earth's surface and encompasses about half of the global sea surface. We have ~2,000 different languages and ~30,000 islands. The Pacific is so diverse that its ecosystems make up one of the world's biodiversity hotspots, with a large number of species found only in the Pacific and nowhere else. In fact, there are 2,189 single-country endemic species recorded to date. Of these species, 5.8 per cent are already extinct or exist only in captivity. A further 45 per cent are at risk of extinction. We face some of the highest extinction rates in the world.

The largest cause of extinction of single-country endemic species in the Pacific is the impact of invasive species. Invasives also severely impact our economies, ability to trade, sustainable development, health, ecosystem services, and the resilience of our ecosystems to respond to natural disasters.

Fortunately, we can do something about it.

Even in our diverse region, we share many things in common. We are island people, we are self-reliant, and we rely heavily on our environment to support our livelihoods. We also share many common invasive species issues as we are ultimately connected. Sharing what we learn regionally makes us and our families benefit economically, culturally, and in our daily lives.

The "Invasive Species Battler" series has been developed to share what we have learned about common invasive species issues in the region. They are not intended to cover each issue in depth but to provide information and case-studies that can assist you to make a decision about what to do next or where to go for further information.

The SPREP Invasive Species Team aims to provide technical, institutional, and financial support to regional invasive species programmes in coordination with other regional bodies. We coordinate the Pacific Regional Invasive Species Management Support Service (PRISMSS), the Pacific Invasive Learning Network (PILN), a network for invasive species practitioners battling invasive species in Pacific countries and territories, and the Pacific Invasives Partnership (PIP), the umbrella regional coordinating body for agencies working on invasive species in more than one Pacific country.

For knowledge resources, please visit the Pacific Battler Resource Base on the SPREP website: https://brb.sprep.org/

Thank you for your efforts,

SPREP Invasive Species Team

About This Guide

This Battler Series publication supports environmental managers to control invasive marine species in the Pacific, including how to prevent them from arriving, how to identify them, and which invasive marine species are the greatest priority for the Pacific region. Use this guide as an accompaniment to the Pacific Marine Biosecurity Toolkit. We thank Henry Lane and Kimberley Seaward of the New Zealand National Institute of Water & Atmospheric Research (NIWA) for preparing this guide.

For a site-based approach to managing marine invasive species in protected areas, see the Battler publication: *Battle Invasive Species that Threaten Marine Managed Areas*.

What are invasive marine species?

Invasive marine species are organisms that are introduced to parts of the world where they do not naturally occur and which have negative impacts on people, the environment, or resources. Negative impacts from invasive marine species include outcompeting native species and driving economic impacts, such as through the loss of commercial fisheries or aquaculture harvest. Not all non-native species are 'invasive'. Non-native marine species can come from many taxonomic groups, such as fish, crabs, oysters, mussels, seaweeds, barnacles, or sponges.

Invasive species have been introduced to Pacific islands across terrestrial, freshwater, and marine systems. There is less information on invasive marine species in the Pacific and their impacts on native ecosystems and economies compared to terrestrial and freshwater ecosystems (Russell and Kueffer 2019). Some terrestrial invasive species can impact coastal marine ecosystems. For example, invasive rats alter coastal forests, and pigs impact water quality in nearshore waters through rooting behaviour. However, this Battler guide covers only marine-dwelling invasive species.

Invasive marine species live and/or reproduce in waters with a wide range of salinities, which includes marine environments such as marshes, lagoons, nearshore coral reefs, mangroves, ports, harbours, and the open ocean.

Invasive marine species may be introduced intentionally, as a source of food or other resources for humans. For example, the red seaweed *Kappaphycus alvarazii* was introduced to many countries throughout the Pacific for aquaculture. The expected outcomes of seaweed farming were not realised for many areas; instead, in some places, particularly in Hawai'i, introduced seaweeds have become threats to marine ecosystems, smothering coral reefs and outcompeting native species.

Non-native marine species can also be introduced unintentionally by human activities such as shipping, including commercial cargo, fishing, and cruise ships. Invasive marine species can also be translocated unintentionally with stock or equipment movements associated with aquaculture. Marine plastic pollution has emerged as a serious environmental issue in the Pacific, and marine plastics can also act as an important pathway for the spread of marine species through biofouled debris and plastic waste (Miller et al. 2018).

When a species is introduced into a new location, it can quickly establish a population and become abundant, increasing the risk of it out-competing native species for resources, jeopardising economies, and harming human health. The introduction, spread, and establishment of invasive marine species to the Pacific region is a serious threat to Pacific flora and fauna and the communities that depend on them. The Pacific islands are vulnerable to impacts of invasive marine species because:

- the Pacific Island marine and coastal ecosystems, such as estuaries and mangroves, coral atolls and coral reefs, lagoons, and open oceans, are home to plant and animal species that are not found anywhere else on earth; and
- the marine environment of the Pacific region supports subsistence and high-value commercial fisheries, eco-tourism, and traditional cultural practices, underpinning livelihoods and economies throughout and beyond the Pacific islands.

Invasive marine species pose a threat to the health of the marine environment throughout the Pacific region, impacting the livelihoods and quality of life of Pacific island people.

The impacts of invasive marine species in the Pacific region are less well known than those of terrestrial and freshwater invasive species. Mostly, this is because non-native marine species are less obvious than in land or freshwater systems and baseline surveys that can identify unusual changes in marine species are carried out infrequently. This guide provides an introduction on how to manage invasive marine species in the Pacific.

Why should we protect Pacific islands from invasive marine species?

With roughly 90 per cent of all Pacific islanders living within five kilometres of the marine environment (excluding Papua New Guinea; Andrew et al. 2019), a healthy marine environment is critical to the environmental, economic, and socio-cultural well-being of Pacific peoples. Nearshore marine environments such as mangrove forests, seagrass beds, and coral reefs are uniquely important for Pacific people who collect and use marine plants, crabs, shellfish, and other resources for food, economic activities, cultural practices, and both cultural and commercial art.

Pacific island countries and territories maintain resource rights and management over approximately 27 million square kilometres of ocean, totalling 20 per cent of the global exclusive economic zones (EEZ). The combined EEZs of the Pacific island countries and territories include:

- around 25 per cent of the world's coral reefs and roughly 4 per cent of the world's mangroves (Bhattarai and Giri 2011);
- about 30 per cent of the world's tuna catch, bringing employment and economic benefits (SPREP 2021); and
- the healthiest remaining global populations of many threatened marine species, such as humpback whales and sea turtles; in addition to their intrinsic value, these species are culturally important and economically important, such as through tourism.

The Pacific region has historically been geographically isolated yet is increasingly becoming connected to the world with increased maritime traffic. The historic geographic isolation leaves the Pacific islands particularly vulnerable to adverse impacts from invasive marine species.

Protection from invasive species has economic benefits. For example, the black-striped mussel *Mytilopsis sallei* is native to the Caribbean and a priority invasive species in the Pacific region. It was discovered in Darwin, Australia, but it was possible to eradicate through early detection and response. Had the intervention not been successful, up to AUD 286 million of damage to port and coastal infrastructure may have been caused through dense fouling (Summerson et al. 2013). Such damage occurring in the Pacific islands would severely impact commerce and tourism throughout the region.

Native species to the Pacific islands and the cultural practices of the local peoples have evolved to fit the Pacific marine environments. As a result, the introduction of invasive marine species may displace or outcompete native marine species populations, degrade the marine environment, and impact local livelihoods and the ability to carry out traditional cultural practices.

Can native species become invasive?

Native species that experience a range extension or unnatural population increase in response to intentional or unintentional human action are referred to as neo-native species. Neo-native species can become a nuisance pest species, negatively impacting the environment and often requiring active management. Neo-natives are distinguished from non-natives because non-natives are introduced (either intentionally or unintentionally) into areas outside of their pre-human distribution.

The crown-of-thorns starfish (sea star) (COTS) is native to the Indo-Pacific region. COTS are pest species when their population significantly increases (see Box 1). COTS consume coral, with COTS outbreaks causing substantial losses in coral coverage and impacting the organisms that rely on healthy coral for food and shelter. The venomous spines on the surface of COTS are also a threat to human health. COTS is an example of a neo-native species and is under management throughout the Pacific.

CASE STUDY 1 Management of crown-of-thorn starfish in the Pacific

Coral-eating crown-of-thorns starfish (sea star) (COTS) *Acanthaster* spp. is a large starfish (up to 45 centimetres across) that is native across the Indo-Pacific region. Population outbreaks of COTS contribute to coral reef decline, leading to major alterations of ecosystems and cascading negative impacts on coral reef-associated fish and invertebrate species.

A key trigger for a COTS population outbreak is warming water temperature, which drives COTS reproduction (Babcock et al. 2016). When high reproduction combines with algal blooms, driven by increased nutrient input from land, conditions are right for COTS to develop, grow, and survive at a much higher rate, leading to a population outbreak.

Management programmes are in place for COTS throughout the Pacific islands. A government-led monitoring programme in Guam, known as the COTS Outbreak Response Plan, was developed collaboratively by multiple and federal agencies. Its aim is to ensure effective and efficient use of resources when responding to a COTS outbreak.

Preventing and managing COTS outbreaks is the most effective way to reduce coral loss and minimise impacts, exactly like managing any invasive marine species. Local observations by experts and the community are a critical part of early detection. In Guam, a response coordinator collates detection data and reports back to the response team and stakeholders when a response is needed.

Community-based reporting is a vital component of early detection and effective management in marine biosecurity. Properly trained community members can significantly enhance the early detection capacity for the Pacific region. The Eyes of the Reef Marianas (EOR) program launched in December 2015 provides residents of Guam a mechanism for reporting observed reef impacts. A two-hour training session teaches participants how to identify among other things, COTS outbreaks, and how to report these findings through an online form. As of December 2017, over 200 participants had completed the training course, with the most recent training occurring in October 2019.

The EOR program is designed to maximise the number of 'eyes on the reef', increasing the chance of detecting COTS outbreak early and thereby maximising the chance of effective management. Without the EOR program, COTS outbreaks may not be detected until scientific surveys and monitoring are carried out, slowing response actions and lowering the chance of controlling the outbreak.

Crown-of-thorns starfish. Credit: NOAA Fisheries

How can invasive marine species be prevented?

It is costly and difficult to control invasive marine species once they have established in a new marine environment. Preventing their accidental or intentional introduction is the most cost-effective method of managing invasive marine species. The Battler guide *Protect Our Islands with Biosecurity* shows a representation of the invasion curve which demonstrates how the costs per species are lower for prevention than for management of established invasive marine species.

Prevention relies on (1) blocking the movement of invasive species along introduction pathways and (2) managing the conditions of receiving environments, where healthy, biodiverse ecosystems are less welcoming to invaders.

Marine species move about the oceans naturally, either by active swimming or by passively hitching a ride on a log, seaweed, or other floating objects, driven by the wind or currents. Human activity, particularly shipping, has increased the distances over which marine species can travel and the frequency and rate at which they are moved to different parts of the world. Marine plastic pollution can facilitate the wider dispersal of marine species beyond their natural range.

Pacific island countries and territories are heavily dependent on shipping for commerce. Shipping is the largest contributor to the spread of marine species around the world. Invasive marine species can be transported within a ship's ballast water or attached to a ship's hull or gear as biofouling.

The Pacific Marine Biosecurity Toolkit includes three resources to guide port authorities and biosecurity managers:

- instructions for performing a biofouling risk assessment to ascertain which ships may pose a higher risk of introducing an invasive marine species to a country. The assessment is based on vessel information, travel history and amount of biofouling (see Document A). Such assessments should be done preferably before entry into local waters or promptly after entry;
- an introduction to the International Convention for the Control and Management of a Ships' Ballast Water and Sediment and how to assess a ship's ballast water management plan (see Document B); and
- a ballast water risk assessment to help determine the level of risk that the ballast water of different ships may pose to a country or territory and whether the ballast water is likely to contain invasive marine species (see Document D).

The risk of introduction of an invasive marine species across the Pacific region is probably lower than the risk for temperate areas because of higher biodiversity in the Pacific islands (Wells and Bieler 2020). More biodiverse ecosystems limit the ability of invasive species to colonise and become established compared to less biodiverse areas (Wells and Bieler 2020). Maintaining a biodiverse marine environment can strengthen the Pacific islands resilience to invasive marine species, providing another incentive for ensuring a healthy marine environment.

Human-driven actions such as climate change, increased nutrient flows, and marine pollution are putting strain on native Pacific marine fauna and flora, increasing the vulnerability to species invasions. In Apia Harbour, Samoa, two invasive algal species *Codium arenicola* and *Spatoglossum macrodontum* were found growing prolifically in marine environments disturbed by human-driven coastal developments (Skelton et al. 2008). Warming water associated with climate change may create more favourable environments for invasive species to establish; for example, coral die-off may provide opportunities for other species to invade and establish.

Protecting native marine species and environments can lower the risk posed by invasive marine species in the Pacific region. Specifically, we can fight against marine species invasions through reducing nutrient pollution, reducing marine pollution including plastics, and reducing greenhouse gas emissions or drawing down carbon dioxide.

CASE STUDY 2 Tuvalu's National Ballast Water Management Strategy

Ballast water is used to provide stability to a ship, allowing it to operate safely under different loading conditions. It can also transport many different marine plants and animals of all life stages. If ballast water pumped onboard a vessel in port is discharged at a different location, it may release marine organisms in the ballast water, introducing marine organisms into new areas (Figure 1). The Pacific region is heavily dependent on shipping for commerce and trade, with shipping records showing frequent movement between Pacific islands and Pacific Rim countries (Lane et al. in press). The introduction of invasive marine species by ballast water, particularly by transit shipping undertaking exchange of ballast water at sea in order to protect countries outside of the Pacific region, represents a major pathway of concern for invasive marine species in the Pacific (SPREP 2015).

The International Convention for the Control and Management of Ships' Ballast Water and Sediments (also known as the Ballast Water Convention or BWM Convention) is an international maritime treaty that requires international vessels that carry ballast water to conform to certain standards of treating ballast water prior to discharge, as approved by the International Maritime Organisation (IMO). All vessels must meet these standards by September 2024. Several Pacific island countries have already ratified the BWM Convention. For details, see Document B of the Marine Biosecurity Toolkit.

National ballast water management strategies are available for the Cook Islands, Fiji, Republic of the Marshall Islands, Samoa, Tonga, and Tuvalu. The purpose of the strategies is to establish a work plan and system to monitor the implementation of the management of ballast water to minimise the risk of invasive marine species introduction without negatively impacting trade. Management of ballast water is a key facet of managing marine biosecurity.

Tuvalu developed a *National Ballast Water Management Strategy* in 2015. The strategy was developed in accordance with international GloBallast guidelines (Tamelander et al. 2010). The Department of Environment and the Marine and Port Services Department are the joint leading agencies for strategy. The benefits of developing this strategy, and others like it, are a clear workplan, timeline, and responsibilities for implementing the BWM Convention. The *National Ballast Water Management Strategy* of Tuvalu has the following priorities:

- provide an appropriate forum to oversee and review implementation of the *Strategy*,
- develop legislation to give full effect to the BWM Convention,
- undertake additional baseline survey work and, based on survey results, consider the need for Risk and/or Economic Impact Assessment,
- conduct an awareness campaign on ballast water management issues, and
- undertake capacity building in Tuvalu to ensure effective implementation of the BWM Convention.

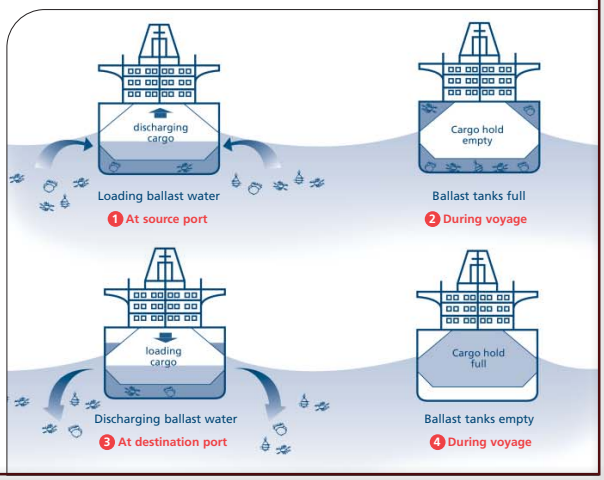

FIGURE 1. Cross section of a ship showing ballast tanks and ballast water exchange cycle. Credit: GloBallast/IMO.

How can we find marine invasions?

Regular monitoring is critical to early detection of invasive marine species. Early detection can enable a rapid response to prevent the new introduction from becoming established and causing negative impacts. It is difficult to manage marine biosecurity without knowing what marine organisms are present in a location.

Monitoring should be conducted at intervals that maximise the chances of detection. Repeat surveys every six months (bi-annually) will detect temporal changes in species assemblages. Some marine organisms have life cycles that mean they are only visible without equipment at certain times of the year; therefore, it is recommended to survey during both warmer water and cooler water seasons. Geographically expansive biological monitoring programmes can be expensive, so it is recommended to identify high-risk locations such as ports and harbours and concentrate on these areas.

Surveys of invasive marine species can be achieved using the guidance Document C and the Species ID guide in the Pacific Islands Marine Biosecurity Toolkit. Document C of the Marine Biosecurity Toolkit guides the user on how to find non-native marine species, which could be during structured surveys or opportunistic encounters during activities such as scientific dive surveys, shoreline searches, and harbour biodiversity monitoring.

The public can also find invasive marine species by simply being around the water and observing. Community education and engagement can significantly increase the ability within a country to detect new invasive marine species, as has been demonstrated by the EOR program for detecting COTS outbreaks (see Box 1). The Marine Biosecurity Toolkit is an introductory educational resource to marine biosecurity, but this should be supported by other educational programs or marine biosecurity campaigns that raise awareness (see the Battler guide *Campaign to Battle Invasive Species in the Pacific*).

Sun cup coral (*Tabastraea tagusensis*) can be spread by biofouling and ballast water contamination. Contact with this invasive coral can kill native corals. Credit: Alexandre Ornella from ICMBio

How do we identify invasive marine species?

Suspected non-native marine species can be observed and/or collected during planned surveys or by chance. Sampling guidance (Document C) is included within the Pacific Islands Marine Biosecurity Toolkit. The sampling guidance document provides information on how sampling can be conducted in the field to detect new marine species in the Pacific. The sampling guidance is based on rapid assessment surveys, which have the primary aim of detecting introduced, cryptogenic, and native species to collect baseline data (Campbell et al. 2007). Rapid assessment surveys rely on collecting specimens that are easily reached, for example on the sides of floating docks, intertidal zones, or on rope that can be pulled out of the water.

The sampling guidance document includes protocols for three sampling locations:

- Ports and marinas are priority sites because these are often the first places where invasive marine species occur after being introduced by ships. They are also easily accessible and contain a large number of structures that commonly have biofouling.
- Rocky intertidal sites are important because benthic organisms can be observed at low tide.
- Roving dive surveys enable open water species to be observed, and volunteers can easily incorporate such surveys into their recreational dives.

Appendix 1 of Document C of the Marine Biosecurity Took includes a data sheet for recording data collected during a survey. The Species ID guide within the Marine Biosecurity Toolkit will assist with identifying priority invasive marine species to the Pacific.

Online resources for identifying invasive marine species can be useful in addition to the Species ID guides. Several online resources provide images and information to help with identification, such as the National Introduced Marine Pest Information System (NIMPIS), FishBase, and CABI Invasive Species Compendium. The New Zealand marine pest ID guide may also be useful.

Invasive marine species can be challenging to identify. Some groups of marine taxa are more challenging to identify than others. For example, marine sponges can be challenging to identify because many non-native sponge species lack strong features that allow them to be distinguished from similar native species.

Taxonomic identification should be to the species level for the purposes of marine biosecurity. Inaccurate identification could lead to missing new introductions, which slows or prevents a rapid response to a marine biosecurity incursion. Ideally, species identification should be confirmed by a taxonomic expert, and a list of experts should be created for consultation and submission. The PRISMSS team can help Pacific managers connect with taxonomic experts.

After a species has been identified with reasonable certainty as an introduced species, an individual may need to be collected for taxonomic verification. Collection should be done by trained staff, avoiding destructive collection that may harm native species. Specimens collected for further identification by experts need to be preserved correctly. Appropriate substances and concentrations for preserving specimens are included in Appendix B of Document C of the Marine Biosecurity Toolkit. Incorrect preservation of specimens can damage important structures that are used to identify specimens to a species level.

CASE STUDY 3 Biological baseline survey of Apia Harbour, Samoa

Biological baseline surveys are useful to gather information on marine biodiversity within an area, highlighting what species are present and providing a benchmark of species abundance and composition for future monitoring programs. Biological baseline surveys for marine environments have been carried out in some Pacific island countries and territories, including American Samoa, Guam, Palau, Samoa, and the remote Palmyra Atoll.

A baseline survey carried out at the main berth in Pago Pargo Harbour, American Samoa, reported 17 marine non-native species composing 10 per cent of the total biota identified at that site (Coles et al. 2003). Much less is known about the status of invasive marine species in those countries and territories that have not carried out biological surveys.

The patterns of ship movements into and around the Pacific region have important implications for the introduction and translocation of invasive marine species. The high volume of maritime traffic to Pacific islands from Pacific Rim countries as well as inter-island movement presents opportunities for ongoing species translocations.

A biological survey of Apia Harbour, Samoa, in 2007 identified new marine species records for Samoa and biogeographic extensions for many others (Skelton et al. 2008). Of the 207 taxa identified, 13 were considered introduced to Samoa and nine were cryptogenic. The survey included 11 sites within Apia Harbour, with a focus on the wharf and its surrounding areas.

The Marine Section of the Ministry of Natural resources & Environment provided a preliminary identification of specimens before they were shipped to the University of South Pacific (USP) and to James Cook University, Australia, for further identification by consulting international experts. All specimens collected are archived at the South Pacific Regional Marine Collection at USP. Archiving specimens is important for producing accurate lists of non-native species.

The biological survey of Apia Harbour built local capacity for marine biosecurity in Samoa. Hands-on participation by local government staff during field surveys as well as training on invasive marine species identification were two critical components of knowledge transfer to local people.

The Apia Harbour survey is an excellent example of a biological survey carried out in a high-risk port for purpose of identifying new marine species to Samoa. It highlights the importance of consulting with expert taxonomists to ensure accurate species identification as well as archiving specimens for future reference if required. Such operations enhance local capacity for marine biosecurity.

The alga *Coidum ovale* recorded from Samoa for the first time during a survey of Apia Harbour. Credit: Skelton et al. (2008).

Which invasive marine species are a priority?

All introduced species will have some level of impact, whether it is outcompeting native species, driving economic impacts through loss of commercial fisheries or aquaculture harvests, or even more subtle impacts such as disturbing benthic sediments (the process of living organisms turning over the seafloor is called bioturbation).

Understanding the impacts an invasive marine species has caused in other locations provides a good clue to the impact it may have in the Pacific region.

A list of 25 priority invasive marine species to the Pacific islands and how to identify them are included in the Pacific Islands Marine Biosecurity Toolkit. Information on the biology and ecology, pathways, and impacts are included for each species included in the Species ID guide.

CASE STUDY 4 The introduction of an invasive seaweed to Tuvalu

Sargassum polycystum C. Agardh, 1824 is a brown seaweed that is native to western areas of the Pacific and has been introduced to eastern Pacific countries and territories, including Fiji, New Caledonia, Samoa, Tonga, Tuvalu, and Vanuatu.

In 2012, a sudden proliferation of *S. polycystum* occurred in Tuvalu. *S. polycystum* was first observed on the atoll Funafuti at a port of entry, strongly suggesting that the species was introduced by shipping (N'Yeurt and Iese 2015). The island of Wallis, 700 kilometres to the southeast of Funafuti, was identified as a potential source for the introduction because a large population of *S. polycystum* was known to occur in the Mata Utu harbour of Wallis.

Morphological features of the invasive alga *Sargassum polycystum*. Credit: Yip Zhi Ting

The *S. polycystum* population outbreak in Tuvalu was closely related to nutrient levels in the water directly opposite human settlements. Highly populated areas leach nutrients into the lagoon, fertilising the water and supporting rapid algal growth. The outbreak of *S. polycystum* highlights that what we do on land can affect what happens in the marine environment. In this case, controlling nutrient pollution may help prevent algal outbreaks.

The alga grows in shallow pools (less than 1 metre deep) bordering the coastline. Dense mats of the alga interfere with recreation and commercial use of the waterways. There have been reports of allergic reactions in children after the children swam in alga-infested lagoons. When the abundant, large algae die and decompose, they can smother coral reefs, negatively impacting the habitat and causing a putrid smell that may affect its appeal for tourism (N'Yeurt and Iese 2015).

Aerial view of the coastline of Fongafale, Funafuti, Tuvalu, showing the extensive *S. polycystum* coverage directly against the shoreline. Credit: N'Yeurt and Iese (2015)

What do we do if we find a suspected invasive marine species?

A formal reporting system for an invasive marine species should be in place for each Pacific island country and territory. Reporting non-native species usually goes to the government agency in charge of biosecurity. For example, in New Zealand, Biosecurity New Zealand monitors a pest and disease hotline 24/7, where callers report unusual organisms, including both terrestrial and marine organisms. Reports of suspect invasive species are sent to an investigator who follows up on the report before taking any appropriate action. While a type of phone hotline is beneficial because it allows the user to directly communicate with a trained operator, other types of reporting mechanisms may also be useful. Options may include interactive website report forms, such as that used by the California Department of Fish and Wildlife, or a drop-in kiosk.

Informal reporting can also be a resource, if managers routinely check for new reports. The free application iNaturalist allows users to report species, although there are no direct lines of responsibility ensuring action is taken regarding a reported sighting. Users can tag a new sighting for inclusion in some existing iNaturalist projects focused on invasive species, and anyone can create a new project, such as a project targeting a protected area, an island, or a group of species. Example projects include: 'Major invasive plant species in protected areas globally', iMapInvasives: USA and Canada Invasive Species (including the state of Hawai'i); and Seaweeds of New Zealand. National invasive species managers might consider creating a new iNaturalist project for their country, encouraging users to tag species sightings to the project. See: www.inaturalist.org

Any system for reporting an invasive species requires clear lines of responsibility for decision-making, as well as adequate training of staff to assess the reports. National Invasive Species Strategy and Action Plans (NISSAP) are important documents to facilitate coordinated and effective biosecurity in a country or territory. A NISSAP should clearly outline roles and responsibilities of different agencies, critical to an effective system for reporting invasive marine species and responding to those reports.

Document E of the Marine Biosecurity Toolkit provides a quick reference summary of potential management strategies for the priority marine invasive species that could arrive in a Pacific island country or territory. It is important to note that it is not always possible to remove an invasive marine species once has been detected. Successful eradication or management will depend on its abundance and how far it has spread. This is why prevention is so important in marine biosecurity. Preventative measures for invasive marine species can be found in Documents A, B, and D in the Marine Biosecurity Toolkit.

Who is responsible for marine biosecurity in the Pacific?

Preventing invasive marine species introductions requires a combination of multiple approaches, including operational procedures, particularly for ships and ports; monitoring and inspection; certification, training, and education; as well as clear roles, responsibilities, and mandates. Policies, strategies, legal frameworks, and institutional coordination that are appropriate on a national, regional, and international level help guide the management of marine biosecurity.

Strategic documents such as a National Ballast Water Management Strategy and NISSAPs are critical to ensuring invasive species management is coordinated within a country or territory. NISSAP exist for Niue, Republic of Marshall Islands, Samoa, and Tonga; a NISSAP for Tuvalu is underway at the time of writing in early 2022. These strategic documents can be found at the Battler Resource Base at https://brb.sprep.org. A Battler guide provides instructions on how to develop a NISSAP; see: Develop a National or Territorial Invasive Species Strategy and Action Plan.

The effective implementation of a NISSAP requires acknowledging responsibilities and expertise of various authorities in order to compile the necessary information and implement the necessary actions. Your country's NISSAP is the starting place to find out who holds the roles and responsibilities for biosecurity within its jurisdiction.

Everyone has a role to play in marine biosecurity in the Pacific. Although government agencies coordinate and monitor the management of biosecurity within a jurisdiction, their efforts can be strengthened when community members are equipped to report suspect invasive marine species. Successful citizen scientist campaigns have been used to help manage COTS across Fiji, New Caledonia, and Vanuatu (Dumas et al. 2020). Capacity-building local activities, such as biological monitoring, can also be paired with training sessions in species identification, a method achieved in Samoa (Skelton et al. 2008).

Raising awareness about marine biosecurity is similar to raising awareness of terrestrial biosecurity issues. More information can be found in the Battler guide *Campaign to Battle Invasive Species in the Pacific*.

In the case of establishment of a marine invasive species, it may be possible to build a case for action from the individual, institution, or industry at fault, similar to the 'polluter pays' principle. It can be difficult to identify the specific cause, time, or instance of an invasive species introduction, just as it may be difficult to quantify the damages caused by the species invasion. Adherence to biosecurity regulations, regular monitoring, and data custodianship are essential to create a strong foundation for action requests.

Thank you for taking on the fight against invasive marine species.

Key terms and acronyms

Ballast water	Water held in the ballast tanks and cargo holds of ships to provide stability and manoeuvrability during a voyage when ships are not fully loaded with cargo.
Benthic	Living on, in, or attached to the seafloor or a surface.
Biofouling	The growth and accumulation of organisms on immersed ship surfaces or structures.
BWM Convention	The International Conventional for the Control and Management of Ships' Ballast Water and Sediments
COTS	Crown-of-thorn starfish (sea star), *Acanthaster* spp.
Cryptogenic	A species of unknown origin that is not demonstrably native or introduced.
GloBallast	Global Ballast Water Management Programme
IMO	International Maritime Organisation
Incursion	Single arrival event of an invasive species in a new environment.
Invasion curve	A comparison of eradication potential and cost of control over time, commonly demonstrating that eradication of an invasive species becomes less likely and control costs increase as an invasive species spreads over time.
Invasive species	Introduced species that have negative impacts on the environmental, economy, or human interests.
Neo-native	A native species that through human actions – intentionally or unintentionally – has experienced a range extension or population outbreak leading it to become invasive.
Non-native	A species introduced outside its natural range.
NISSAP	National Invasive Species Strategy and Action Plan
Pathway	The way in which an organism can be transported into a country.
PRISMSS	Pacific Regional Invasive Species Management Support Service

For more information

The Battler Resource Base contains information and materials for battling invasive species in the Pacific. Information on invasive species management in the Pacific can be found on the SPREP website. Additional information on invasive species management can be obtained from PRISMSS.

The Pacific Islands Marine Biosecurity Toolkit as well as a desktop review of marine invasive species in the Pacific can be found at https://brb.sprep.org/marine-biosecurity-toolkit.

International guidelines on ballast water management can be found at the GloBallast website. International guidelines on ship biofouling can found at the GloFouling website.

A glossary of terms relevant to biosecurity in general is available from the global website of the Convention of Biological Diversity.

Key references

Andrew NL, Bright P, de la Rua L, Teoh SJ, Vickers M (2019) Coastal proximity of populations in 22 Pacific Island Countries and Territories. *PLOS One* 14(9):e0223249. DOI: 10.1371/journal.pone.0223249

Babcock RC, Dambacher JM, Morello EB, Plagányi ÉE, Hayes KR, Sweatman HP, Pratchett MS (2016) Assessing different causes of crown-of-thorns starfish outbreaks and appropriate responses for management on the Great Barrier Reef. *PLOS One* 11(12):e0169048. DOI: 10.1371/journal.pone.0169048

Bhattarai B, Giri CP (2011) Assessment of mangrove forests in the Pacific region using Landsat imagery. *Journal of Applied Remote Sensing* 5(1):053509. DOI: 10.1117/1.3563585

Campbell ML, Gould B, Hewitt CL (2007) Survey evaluations to assess marine bioinvasions. *Marine Pollution Bulletin* 55(7):360–378. DOI: 10.1016/j.marpolbul.2007.01.015

Coles S, Reath P, Skelton P, Bonito V, DeFelice R, Basch L (2003) Introduced marine species in Pago Pago Harbor, Fagatele Bay and the national park coast. Bishop Museum Technical Report No 26.

Dumas P, Fiat S, Durbano A, Peignon C, and others (2020) Citizen Science, a promising tool for detecting and monitoring outbreaks of the crown-of-thorns starfish *Acanthaster* spp. *Scientific Reports* 10(1):291. DOI: 10.1038/s41598-019-57251-8

Lane HS, Seaward K, Inglis G (In Press) Marine non-indigenous species in the Pacific islands: a desktop review. Apia, Samoa: Secretariat of the Pacific Regional Environment Programme.

Miller JA, Carlton JT, Chapman JW, Geller JB, Ruiz GM (2018) Transoceanic dispersal of the mussel *Mytilus galloprovincialis* on Japanese tsunami marine debris: An approach for evaluating rafting of a coastal species at sea. *Marine Pollution Bulletin* 132:60–69. DOI: 10.1016/j.marpolbul.2017.10.040

N'Yeurt AD, Iese V (2015) The proliferating brown alga *Sargassum polycystum* in Tuvalu, South Pacific: assessment of the bloom and applications to local agriculture and sustainable energy. *Journal of Applied Phycology* 27(5):2037–2045. DOI: 10.1007/s10811-014-0435-y

Russell JC, Kueffer C (2019) Island biodiversity in the Anthropocene. *Annual Review of Environment and Resources* 44:31–60. DOI: 10.1146/annurev-environ-101718-033245

Skelton PA, South GR, Seeto J (2008) Marine invasive species survey of Apia Harbour, Samoa. Samoa: National Marine Biodiversity Conservation Project.

SPREP (2015) Pacific Ocean pollution prevention programme (PACPOL): Strategy and work plans 2015-2020. See p 60. Apia, Samoa: Secretariat of the Pacific Regional Environment Programme.

SPREP (2021) State of environment and conservation in the Pacific islands: 2020 regional report. See p 156. Apia, Samoa: Secretariat of the Pacific Regional Environment Programme.

Summerson R, Skirtun M, Mazur K, Arthur T, Curtotti R, Smart R (2013) Economic evaluation of the costs of biosecurity response options to address an incursion of *Mytilopsis sallei* (black-striped mussel) intro Australia. ABARES Report to client prepared for Plant Health Australia, Canberra, September.

Tamelander J, Riddering L, Haag F, Matheickal J, No GMS (2010) *Guidelines for development of a national ballast water management strategy*. GloBallast Partnerships Project Coordination Unit, International Maritime Organisation.

Wells FE, Bieler R (2020) A low number of introduced marine species at low latitudes: a case study from southern Florida with a special focus on Mollusca. *Management of Biological Invasions* 11(3):372. DOI: 10.3391/mbi.2020.11.3.02

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