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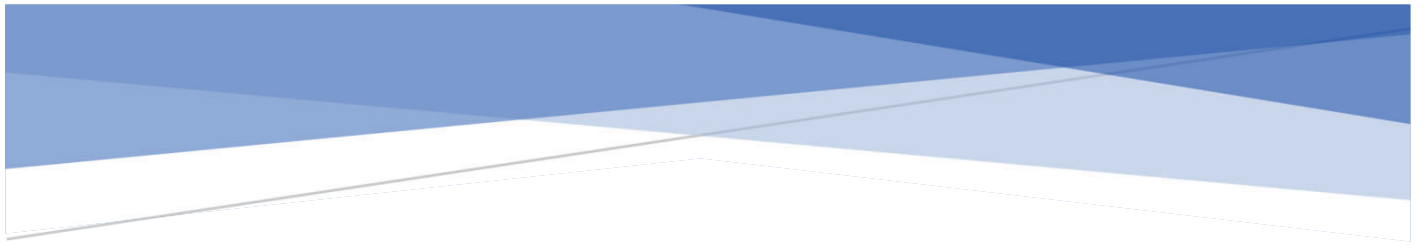
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Marine Invasive Species and Biosecurity in Small Island Developing States



Thesis Submitted by

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Thesis Abstract

Ship biofouling is a major and largely unregulated pathway for marine invasive species (MIS) introductions. Small Island Developing States (SIDS), are highly vulnerable due to reliance on shipping and severe constraints, including limited resources and numerous interlinked regulatory and environmental challenges. Management of MIS is constrained by multiple interlinked challenges, such as environmental complexities, knowledge gaps, ethical–political considerations, inconsistent terminology, and regulatory gaps, which are further compounded by SIDS’ inherent vulnerabilities. They operate across multiple levels, from directly affected systems to broader temporal and global dynamics and the complex feedback between levels will influence the capacity of SIDS to prevent, monitor, and respond to MIS invasions. To address this, I adopted the biosecurity systems framework as the conceptual anchor for this thesis to investigate the challenges and needs of SIDS in managing MIS introduced via ship biofouling and develop context-appropriate strategies to enhance prevention and management capacity.

I achieved this through a mixed-methods approach involving systematic policy reviews, surveys, semi-structured interviews, and documentary analysis across five research phases involving: (1) identification and evaluation of international policy instruments, examining their coverage of MIS categories and introduction pathways while addressing the challenge of inconsistent terminology and regulatory gaps; (2) evaluation of these instruments’ adequacy in relation to SIDS’ three critical management priorities: ecological threats, resource availability, and livelihood implications; (3) assessment of SIDS’ preparedness to manage MIS introductions via ship biofouling, examining current measures, challenges, and needs; (4) evaluation of Australia’s biofouling management framework to identify approaches transferrable to SIDS; and (5) comparison of Mauritius, a Small Island Developing State, and Australia to illustrate differences in implementation capacity and readiness by highlighting structural gaps that constrain SIDS to promote equity and fairness in global marine biosecurity governance.

The policy analysis showed a stronger focus on trade and broad environmental goals than on MIS-specific outcomes is contributing to inconsistent terminology. To promote consistent terminology and support inclusive, adaptable management strategies, especially for SIDS with limited taxonomic capacity, the varied terms in the instruments were grouped into five broad MIS categories. The analysis also showed that the international policies could be leveraged for addressing MIS and strengthen global efforts as most policy instruments address multiple overlapping MIS categories. Overall, these instruments are broadly relevant for all MIS categories introduced through the three critical pathways of trade, shipping, and aquaculture. The pathways addressed by the policy instruments were also categorised and an actionable guidance was developed to strategically match international instruments to specific MIS categories and pathways to promote consistency and reduce regulatory gaps while maximising resource efficiency.

The policy analysis against the three critical management priorities for SIDS showed that existing instruments are insufficient to safeguard SIDS from MIS invasions, primarily because they fail the resource availability criterion. Most instruments demand substantial financial, technical, and human resources, creating significant implementation barriers for SIDS. Additionally, the reliance on voluntary measures and the lengthy, costly process of developing binding instruments contribute to persistent governance gaps across key MIS introduction pathways, including ship biofouling. These limitations highlight the need for pre-border biosecurity measures that can anticipate risks and prevent harmful introductions in the absence of effective binding instruments.

The analysis of SIDS' preparedness showed a widespread failure to recognise the severity of biofouling risks, with only half of the SIDS examined demonstrating adequate awareness. Biofouling management remains incidental and fragmented, dominated by indirect measures, while terrestrial invasive species management continues to receive universal attention with marine focus being limited to a few well-known invasive species. Overall, SIDS have limited capacity and capability to manage ship biofouling, indicating that preparedness is significantly compromised. They are not sufficiently aware, prepared, resourced, responsive, or adaptive to address this pathway. Addressing these challenges will require strengthening legislative and institutional frameworks, building technical capacity, improving data collection systems, securing sustainable financial and human resources, and promoting cross-sectoral collaboration. This shows that SIDS should prioritise cost effective pre-border biosecurity measures and major introduction pathways rather than resource intensive species-specific approaches.

The Australia's biofouling management framework analysis showed that Australia's pre-border biofouling measures are well established, evidence based and represent the most resource-efficient component of its biosecurity system. These measures can be adapted by SIDS without the need to build a complete system from scratch, aligning with their critical management priorities and offering a practical pathway to a resilient biosecurity system without replicating Australia's resource-intensive model. However, even pre-border measures require investment, highlighting the need for targeted training and capacity building, which could be facilitated by the International Maritime Organization in collaboration with Australia. The study also proposes practical system components, including a vessel-clearance process and risk-assessment guides. It also supports international standards allowing only hull grooming as the preferred in-water cleaning method when out-of-water cleaning is not feasible. This will ensure equity, protect SIDS' marine environments, and prevent inconsistent practices that could undermine their biosecurity systems.

Given that ship biofouling is a high-risk pathway for SIDS and remains largely unregulated globally, this thesis provides practical strategies that can be implemented even in the absence of binding measures. The proposed pre-border ship biofouling management framework that follows the biosecurity systems framework can be adapted to other critical pathways and MIS categories by applying the actionable guidance outlined in Chapter 2. Overall, this research, identified systemic

deficiencies in international policy and national capacity that compromise the ability of SIDS to manage MIS introduced via ship biofouling. The core findings emphasise the critical need to shift governance toward mandatory, resource-efficient pre-border measures to achieve equity and strengthen resilience.

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Chapter 1: General Introduction - Marine Invasive Species Management: A Critical and Complex Global Issue

1.1 Marine invasive species – A global threat

Marine invasive species (MIS) are non-indigenous marine plants and animals, including their seeds, eggs, spores or other biological structures, that disrupts coastal, marine, estuarine or brackish ecosystems (Costello et al. 2025; Department of Environmental Conservation 2024; World Shipping Council 2021). They cause the loss of indigenous species through predation, and damage to fishing gears, power station water intakes, ships, port infrastructures and aquaculture facilities (Department of Fisheries 2014, 2016; Early et al. 2016; Graham, WM et al. 2003; Katsanevakis et al. 2014; Pyšek and Richardson 2010; Rajagopal et al. 2006; Robinson, TB et al. 2005; World Shipping Council 2021). Food provision (fishing/aquaculture), ocean nourishment (nutrient recycling etc.), recreation and tourism and lifecycle maintenance are the most negatively affected marine ecosystem services by MIS (Katsanevakis et al. 2014). Despite these significant disruptions, the full extent of marine ecosystem service losses or alterations due to MIS may be underestimated or receive less attention (Cuthbert et al. 2021; Keller. et al. 2011; Ojaveer et al. 2015; Zitoun et al. 2020).

1.1.1 Ecological impacts of MIS

Coastal waters within regions of busy maritime traffic and estuaries, lagoons and bays crowded with marine aquaculture farms, are substantially at risk from alien species invasions (Galil et al. 2009). Zaiko et al. (2006) found that lagoon habitats, such as artificial rock and stone, sand, mud, and habitats modified by shell deposits, had higher numbers of alien species per habitat than areas of open sea, with physical factors, such as salinity, depth range, shallowness of a habitat, availability of a hard substrate and habitat alterations, driving the distribution of both indigenous and invasive species.

Species introduced in new environments often have an advantage because they do not share evolutionary or ecological history compared to indigenous species (Sorte, Williams and Carlton 2010). For instance, introduced species might have few enemies or competitors since they have left behind their traditional predators, parasites and competitors (Sorte, Williams and Carlton 2010). Likewise, they are likely to encounter prey that are naive and have not developed defences against them (Sorte, Williams and Carlton 2010). Together these factors give MIS an advantage when invading the new environment. In fact, when introduced in similar environments, MIS can eliminate indigenous organisms that perform important ecological roles (Makowski and Finkl 2019; Ruiz-Carus et al. 2006). For instance, the availability of abundant food and limited or no natural enemies in Florida's coastal

waters make it a suitable environment for the survival of the ferocious predator *Pterois volitans* (red lionfish) (McGuire and Hill 2021). Their introduction in Florida's coastal waters has caused harm to Florida's coral reef ecosystems. The lionfish has heavily preyed on a range of herbivorous fish and invertebrates causing substantial declines. This has in turn resulted in an increase in algal growth on reef substrates leading to smothering of corals (McGuire and Hill 2021; Ruiz-Carus et al. 2006; Whitfield et al. 2002).

Parasite and host populations can also be directly or indirectly impacted by the introduction of MIS. Introduced species often have an advantage over indigenous species because many parasites of introduced species are lost during the invasion process. At the same time, parasites introduced with invasive species can increase the parasite load of indigenous hosts (Goedknecht et al. 2016).

Even seemingly sessile invasive species may be capable of rapidly spreading from their location of colonisation. For example, *Perna viridis* (Asian green mussel) can settle in water depths of 1m to 7m and use its byssus to detach and re-attach to different types of substrates (Rajagopal et al. 2006). Consequently, it can quickly migrate away from its point of entry, spreading to various adjacent ecosystems such as mangroves, coral reefs, and estuaries (Baker, Baker and Fajans 2004; Rajagopal et al. 1997; Rajagopal et al. 1998; Rajagopal et al. 2006).

1.1.2 Socio-Economic impacts of MIS

Endemic species provide essential services, including contributing to food security. Pacific Islanders, for example, obtain about 50-90% of the protein in their diet from near-shore pelagic and inshore reef and lagoon fisheries (Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP) 2014). These species are not only economically important but are also aesthetically and spiritually significant for island communities (UN-OHRLS 2017). According to Lopez-Rivas and Cardenas (2024) the economic value for coastal and marine ecosystem services is estimated at \$99-\$1535 per hectare per year for provisioning services such as fishing, \$45-\$2170 per hectare per year for cultural services and \$185-\$895 per individual per year for recreation and tourism services.

Livelihood, health and leisure activities, and the survival of coastal communities are, however, threatened by the introduction of MIS, as the resource damages they cause can be significant (GEF-UNDP-IMO GloBallast Partnerships Programme 2017; Katsanevakis et al. 2014; McGuire and Hill 2021; Perry et al. 2005). For example, the loss of coral reefs and economically important indigenous species due to the introduction of the invasive red lionfish has resulted in declines in commercial and recreational fisheries and impacts on tourism activities such as snorkelling and diving, which in turn negatively affected the livelihood of coastal communities (McGuire and Hill 2021). Likewise, the European green crab, *Carcinus maenas*, introduced to the US in the 1950s, preyed on indigenous

scallops and other commercially important shellfish costing the American fishing industry millions of dollars (GEF-UNDP-IMO GloBallast Partnerships Programme 2017; Lovell, Besedin and Grosholz 2007; Mach and Chan 2013). Such examples underscore how invasive species can generate extensive and ongoing economic damage at national scales.

The invasion of certain fouling species can result in machinery and vessel breakdown causing delayed port operations (Department of Fisheries 2014; Grech et al. 2013). Overcoming the hydrodynamic drag caused by hull fouling organisms can account for up to 40–80% of a ship's total fuel consumption resulting in increased expenses and unnecessary greenhouse gas emissions (Fernandes et al. 2016). Overall, the global economic impacts of invasive aquatic species (both marine and freshwater) are estimated at US\$345 billion, with most cost (74%) stemming from resource damages, with a mere 6% attributed to management efforts (Cuthbert et al. 2021). Further examples include invasive fish species that have depleted natural stocks and caused other impacts costing the United States an estimated US\$6.03 billion per year, zebra mussel (*Dreissena polymorpha*) that have caused approximately US\$1.12 billion annually in infrastructure damage and control costs, and aquatic weeds that have resulted in losses, damages, and control costs of about US\$122 million each year (Cusack, Harte and Chan 2009). These cases illustrate how invasive aquatic species can generate both localised and widespread economic burdens, affecting fisheries, infrastructure, and ecosystem services at multiple scales.

1.1.3 Health impacts of MIS

Introduced MIS can cause serious health issues to humans that may even lead to death (Table A1, Chiappi et al. 2025; Tsirintanis et al. 2022). For example, in 1991, the strain of the bacterium *Vibrio cholerae*, that had previously been reported only in Bangladesh, was introduced in three separate ports in Peru causing an epidemic outbreak, which then spread across South America, affecting more than a million people as well as causing the death of more than ten thousand by 1994 (GEF-UNDP-IMO GloBallast Partnerships Programme 2017). Similarly, the invasion of toxin-producing MIS can pose serious toxicological risks on human health (Chiappi et al. 2025; Tsirintanis et al. 2022). For example, some algae species produce toxins that contaminate filter-feeding shellfish, which can cause severe illness and death when they are consumed (Raaymakers and Gould n.d). Consuming seafood that are contaminated by toxins is not the only threat to humans. Encountering certain toxin-producing MIS can also lead to serious health hazards such as excruciating pain, nerve and muscle paralysis, nausea and hallucination amongst others (Table A1, Tsirintanis et al. 2022), thus the need to ensure proper management of their introductions.

MIS can also contribute to the death of indigenous marine species by carrying pathogens. The study conducted by Soppitt et al. (2025) showed that 51.1% of dead shore crabs (*Carcinus maenas*) were carrying pathogens including ostreid herpesvirus-1 microvariant (OsHV-1 μ Var) and *Vibrio* bacteria, compared to 29.4% of living crabs. The presence of OsHV-1 μ Var was significantly higher in dead crabs (24.4%) than in living ones (5.9%), showing that MIS are carriers of disease, potentially increasing mortality among indigenous populations.

1.2 Marine invasive species threat to Small Island Developing States

Small Island Developing States (SIDS) comprise 57 developing nations made up of small islands, spread across three geographic regions, the Caribbean Region, the Pacific Region and the AIS Region (Atlantic, Indian Ocean and South China Sea Region) (UN-OHRLS 2017; United Nations Department of Economic and Social Affairs 2021), (Figure 1.1). These nations obtain their natural resources mostly from the ocean as they are isolated by distance or oceanography (Roberts et al. 2002; World Health Organization 2021). Ecosystem services such as recreation, tourism, fishing, aquaculture and agriculture, that procure significant socio-economic and livelihood benefits to SIDS, are provided by their endemic and native species (Katsanevakis et al. 2014; UN-OHRLS 2017). The geographic remoteness of SIDS makes them predominant centres of endemism and examples of isolated islands with high levels of endemic species include Mauritius and La Reunion in the Indian Ocean, Hawaii and Easter Islands in the Pacific, and St. Helena and Ascension Islands in the Atlantic (Roberts et al. 2002).

SIDS are also considered biodiversity “hotspots” because they have a larger number of endemic species compared to continents (UN-OHRLS 2017). For instance, 476 species listed as threatened species are found in the Pacific SIDS (CEPF 2008). This includes more than half of the world’s known species of whale and dolphin, most of the remaining dugong populations, and six of the world’s seven marine turtle species (Logan 2013; SPREP 2011, 2017, 2018–2022). Consequently, the introduction of MIS in SIDS can disrupt endemic species community of SIDS, which in turn is expected to impact the socio-economic and livelihood values in SIDS. Islands are also known to have more introduced invasive species than countries on continents (McGeoch et al. 2010) and about 10-35 known harmful MIS (Figure 1.2) are already affecting the marine ecoregions of SIDS. SIDS face multiple vulnerabilities that further amplify their exposure to MIS. These include small but growing populations, limited resources, geographic remoteness, susceptibility to natural disasters, vulnerability to external shocks, heavy reliance on international trade, fragile environments, and sensitivity to climate change (UN-OHRLS 2017).

SIDS are highly reliant on international shipping and trade for the export and import of necessary food and other products, on fishing activities undertaken in their maritime zones by international fishing

vessels, on aquaculture for food security, and on tourism development resulting from visits of international recreational yachts and the conduct of recreational sea and water activities (Bush 2018; GEF-UNDP-IMO GloFouling Partnerships 2018; Mauritius Attractions 2008-2021). Hence, three key pathways that can inadvertently transport MIS to SIDS are shipping, trade, and aquaculture with shipping being the major route for marine species introductions (Table 1.1). These vulnerabilities and reliance on high-risk pathways (World Health Organization 2021) exposes SIDS to high risks of MIS invasion, which pose significant ecological threats, impact livelihoods, and strain available resources. Understanding these factors is essential for evaluating the adequacy of existing measures and preparedness of SIDS to monitor, control, and manage MIS introductions which are further explored in Chapters 3 and 4.

Table 1.1 List of introduced species in Small Island Developing States and their introduction pathways (Invasive Species Specialist Group 2015).

Introduced Species	Status	Invasiveness	Introduction Pathway
<i>Tubastraea coccinea</i> (orange-cup coral)	Alien or Cryptogenic	Unspecified	Mobile platforms could have contributed to their dispersal to the Gulf of Mexico oil and gas platforms (Fenner and Banks, 2004, Sammarco et al. 2004).
<i>Pterois volitans</i> (Indo-Pacific red lionfish)	Alien	Invasive or unspecified	Eggs and larvae of the red lionfish may be transported via ballast water (Whitfield 2002).
<i>Crassostrea gigas</i>	Alien	Not invasive	Hull fouling of Commercial Ships
<i>Didemnum spp.</i>	Alien	Invasive	Commercial Shipping (ballast water & Hull Fouling), aquaculture shellfish stock
<i>Gracilaria salicornia</i>	Cryptogenic	Unspecified	Commercial Shipping (ballast water & Hull Fouling)
<i>Gymnodinium catenatum</i>	Unspecified	Invasive	Ballast Water, aquaculture cages and fishing activities
<i>Mytilopsis sallei</i>	Alien	Unspecified	Hull fouling of Commercial Ships
<i>Perna viridis</i>	Alien	Invasive	Commercial Shipping (ballast water & Hull Fouling)
<i>Styela plicata</i>	Alien	Unspecified	Commercial Shipping (ballast water & Hull Fouling)

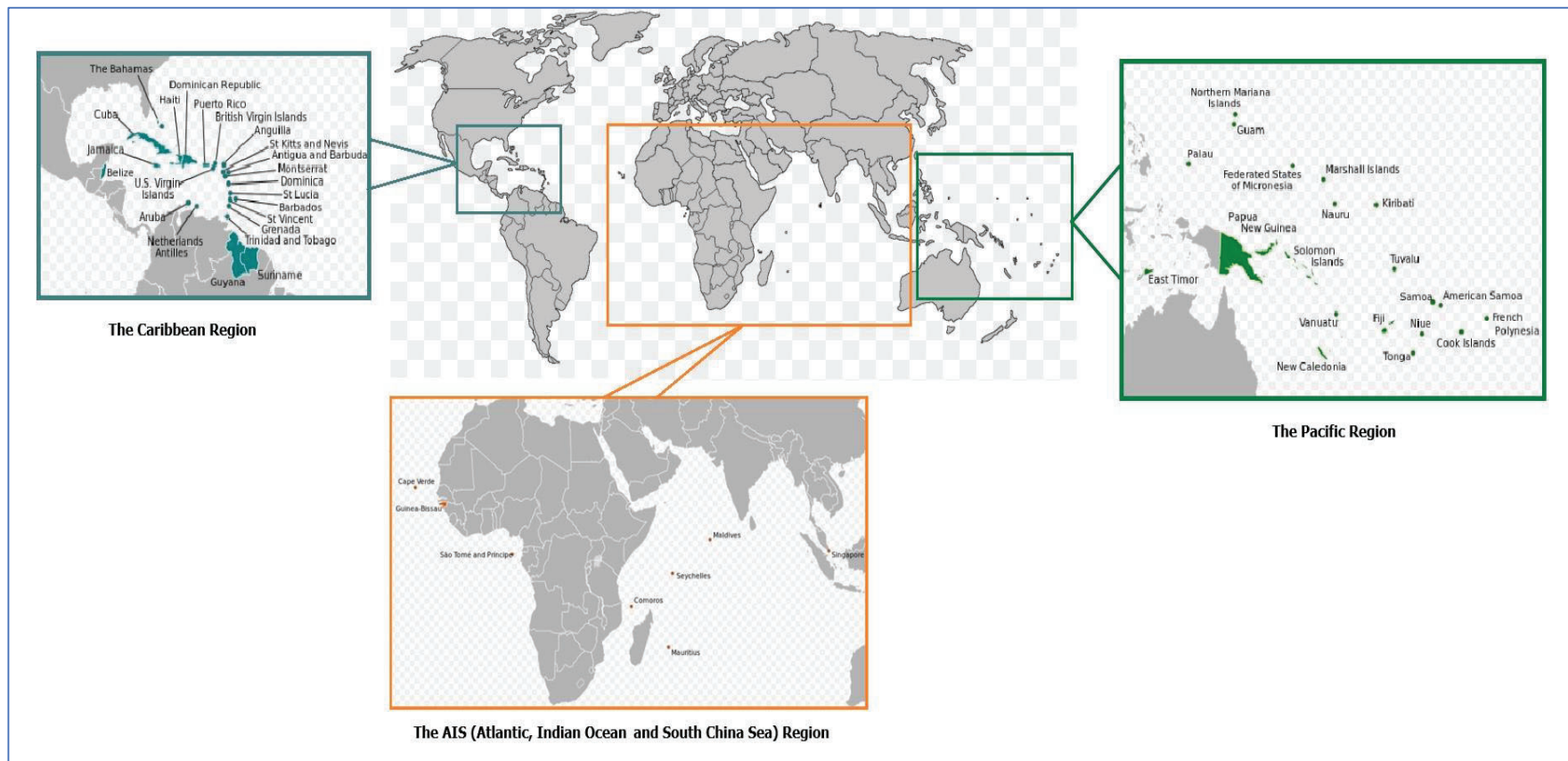


Figure 1.1 Small Island Developing States across the three geographic regions (Image adapted from: [wikimedia.org](https://www.wikimedia.org/) & [PngFind.com](https://www.pngfind.com/))

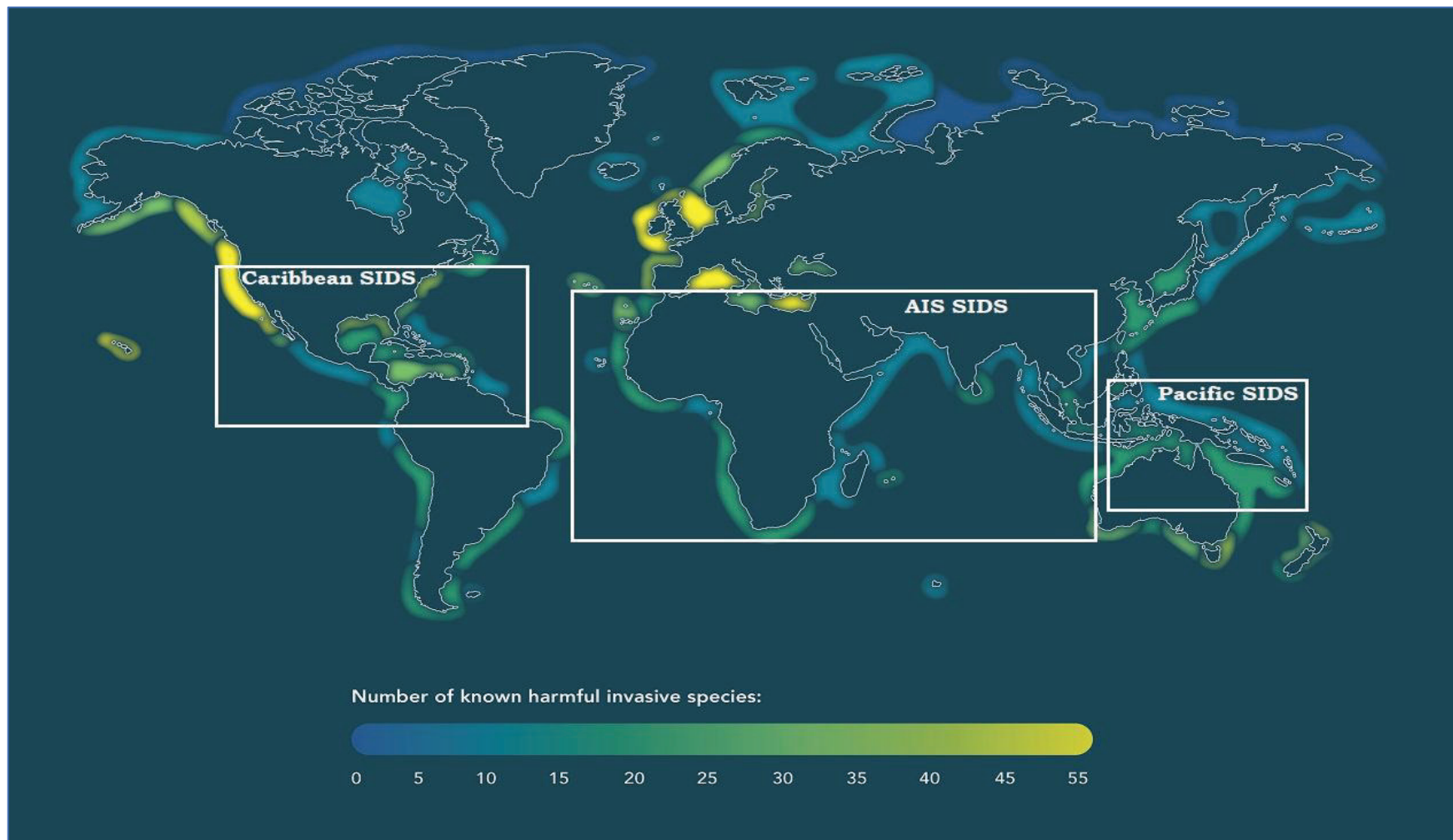


Figure 1.2 Map of SIDS' marine ecoregions that have been impacted by harmful marine invasive species (adapted from Clear Seas 2020).

1.3 Critical issues and complexities in marine invasive species management

1.3.1 Environmental complexities, knowledge gaps, and ethical–political challenges

Species distributions continue to shift in response to introductions by human activities and changes in environmental conditions. While predictions of future invasive species largely depend on historical invasion records, many emerging MIS remain unidentified, making it difficult to anticipate their potential impacts (Essl et al. 2018; Seebens et al. 2018). The classification of invasive species is further complicated by the intersection of ecological and ethical considerations. The use of terms such as “alien” in invasion science raises ethical concerns because it can reflect xenophobic social attitudes, while existing ecological classification systems remain limited in scope, often assessing either a species’ capacity to spread or its ecological impact rather than integrating both dimensions simultaneously (Soto et al. 2024). As such, understanding their spatial and temporal distributions, along with the factors influencing their spread, is critical for strengthening biosecurity frameworks. Despite the growing significance of the issue, invasive species management and biodiversity conservation remain low priorities on the political agendas of many nations. When policies are developed, they typically rely heavily on national boundaries, an approach that is inadequate, as it overlooks key biogeographic factors such as evolutionary histories and the complex ecological relationships of introduced species (Chew and Hamilton 2011; Piria et al. 2021; Soto et al. 2024; Tarkan et al. 2024). In this context, reducing uncertainty in bioinvasion assessments is essential for the effective development and implementation of management strategies. Therefore, clear and consistent terminology that incorporates biogeographic, evolutionary, ecological, and ethical principles is essential to support both scientific understanding and policymaking (Essl et al. 2018; Seebens et al. 2018; Soto et al. 2024; Tarkan et al. 2024).

1.3.2 Lack of simple, clear and standard terminology

Soto et al. (2024) identified 59 different terms used to describe or classify non-indigenous species (see Table 1, from Soto et al., 2024), which surpasses the number reported over a decade earlier. While various international instruments address biosecurity and invasive species control, most are not specifically tailored to MIS. The use of ambiguous or inconsistent terminology in invasion biology often leads to misunderstanding that hinder science communication and undermine the effective conservation of indigenous species as well as the management of non-indigenous species. Terms such as ‘exotic,’ ‘introduced,’ ‘invasive,’ and ‘naturalized’ are used interchangeably despite having distinct ecological meanings. This complicates scientific dialogue and hinders the development of clear and targeted management strategies (Colautti and MacIsaac 2004; Soto et al. 2024; Tarkan et al. 2024). For example, a species labelled as “naturalized” in one region may be perceived as harmless, while in another, it may be considered “invasive” and harmful to local biodiversity. Consequently, without clear

and consistent definitions, policymakers may hesitate to take action or may implement inappropriate control measures, potentially wasting resources and causing unintended ecological consequences (Colautti and MacIsaac 2004; Essl et al. 2018; Soto et al. 2024).

1.3.3 Regulatory gap for critical introduction pathways

Marine invasive species can be introduced through various pathways, including hitchhikers on ships, contaminants on plants, animals and food, aquaculture/mariculture, fishing equipment, floating marine debris, including ghost fishing nets, oil and gas structures, recreational boating, renewable energy structures, deep-sea mining and measuring instruments (Awad et al. 2014; GEF-UNDP-IMO GloFouling Partnerships 2019d; GLOBEFISH 2021; International Maritime Organization 2025b; Lieurance et al. 2023). Among these, three key pathways, *shipping* (e.g., ballast water, ship biofouling, hitchhikers on vessels, and contaminated angling or fishing gear), *trade* (e.g., unintentional release from the pet/aquarium trade, live food, and live bait, contaminant on plants/animals and food contaminants), and *aquaculture* can inadvertently transport MIS to SIDS. Notably, these same three pathways are consistently identified in the literature as the primary routes for aquatic species introductions, with the "transport-stowaway" pathway associated with shipping identified as the most frequent route for marine species introductions (Figure 2.2) (Lieurance et al. 2023).

Given the dominant role of shipping, particular attention has shifted to hull fouling, which has now been identified as an even greater risk for MIS introductions than ballast water (Table 1.2) (GEF-UNDP-IMO GloFouling Partnerships 2019a, 2019b). Therefore, to pursue its effort in protecting the marine ecosystems against the harmful effects of MIS the IMO developed two voluntary instruments, the "2011 Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species" and the 2012 Guidance for minimizing the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft. On 7 July 2023, the 2011 Guidelines were updated and replaced by the 2023 Biofouling Guidelines, which are currently in use (International Maritime Organization 2025b). Despite these efforts, there are still no binding international measures to address ship biofouling, even though it represents one of the most critical MIS pathways.

In April 2025, the IMO announced that work would begin on developing a new mandatory instrument on ships' biofouling management (GEF-UNDP-IMO GloFouling Partnerships 2025). However, the negotiation, approval, and adoption of such a convention will take years to conclude, leaving a significant regulatory gap. This underlines the urgent need for SIDS to adopt proactive and preventive measures to safeguard their marine ecosystems in the interim.

Table 1.2 *Studies demonstrating relative importance of shipping-related pathways for marine invasive species introduction (adapted from GEF-UNDP-IMO GloFouling Partnerships 2018a).*

Author	Location	Ballast water	Biofouling	Both
Cohen and Carlton, 1995	San Francisco	8%	55%	-
Cranfield et al., 1998	New Zealand	3%	69%	21%
Hewitt et al., 1999, 2004	Port Phillip Bay, Australia	20%	78%	-
Eldredge and Carlton, 2002	Hawaii, USA	18 sp.	212 sp.	-
Gollasch, 2002	North Sea	38%	57%	-
Fofonoff et al., 2003	North America	20%	36%	34%
Hewitt et al., 2007	Algae, Worldwide	~12%	~74%	-
Hewitt and Campbell, 2010	Australia	33%	79%	-
Farrapeira et al., 2011	Brazil	34.4%	89.8%	33.8%
Williams et al., 2013	California, USA	21 sp.	43 sp.	-
Chan et al., 2015	Canadian Arctic	7 sp.	18 sp.	-
Lieurance et al., 2023	Florida, USA	2 Taxa	4 Taxa	-
Massé et al., 2023	France	29%	37%	68%

1.4 The need for a “Systems Approach” to MIS management in SIDS

Taken together, these interlinked challenges demonstrate that MIS management in SIDS cannot be explained by any single factor. Instead, they emerge from interactions across ecological, regulatory, socio-political, and global systems. Figure 1.3 adapts Bronfenbrenner’s Ecological Systems Theory to the SIDS context, illustrating how immediate management systems interact with internal vulnerabilities, external drivers, and broader temporal and global forces. The model highlights how feedback between these levels continually shape MIS management outcomes, reinforcing the dynamic and often fragmented nature of current responses. This complexity underlines the need for a structured and integrative way of organising management efforts. Therefore, a systems lens is essential to capture the layered nature of these pressures.

This systematic and integrated framework can be conceptualised as a *biosecurity system*, which consist of a set of management activities that use holistic approaches to protect a country’s biodiversity, human health, leisure activities, and socio-economic values from the adverse effects of pests, pathogens, and diseases (Arthur et al. 2008; Bland, L.M. et al. 2024; Heikkilä 2011; Outhwaite 2010). The harmonised continuum of pre-border, border, and post-border activities of a biosecurity system, supported by

legislative authority, financial and institutional (human, technical and physical) resources, and coordinated governance enhances resilience (Anand 2018; Bland, L.M. et al. 2024; Heikkilä 2011; Outhwaite 2010). These components operate at multiple levels, from individual institutions to national and international scales, encompassing prevention, detection, and control measures to maximise efficiency and reduce risk (Anand 2018; Arthur et al. 2008).

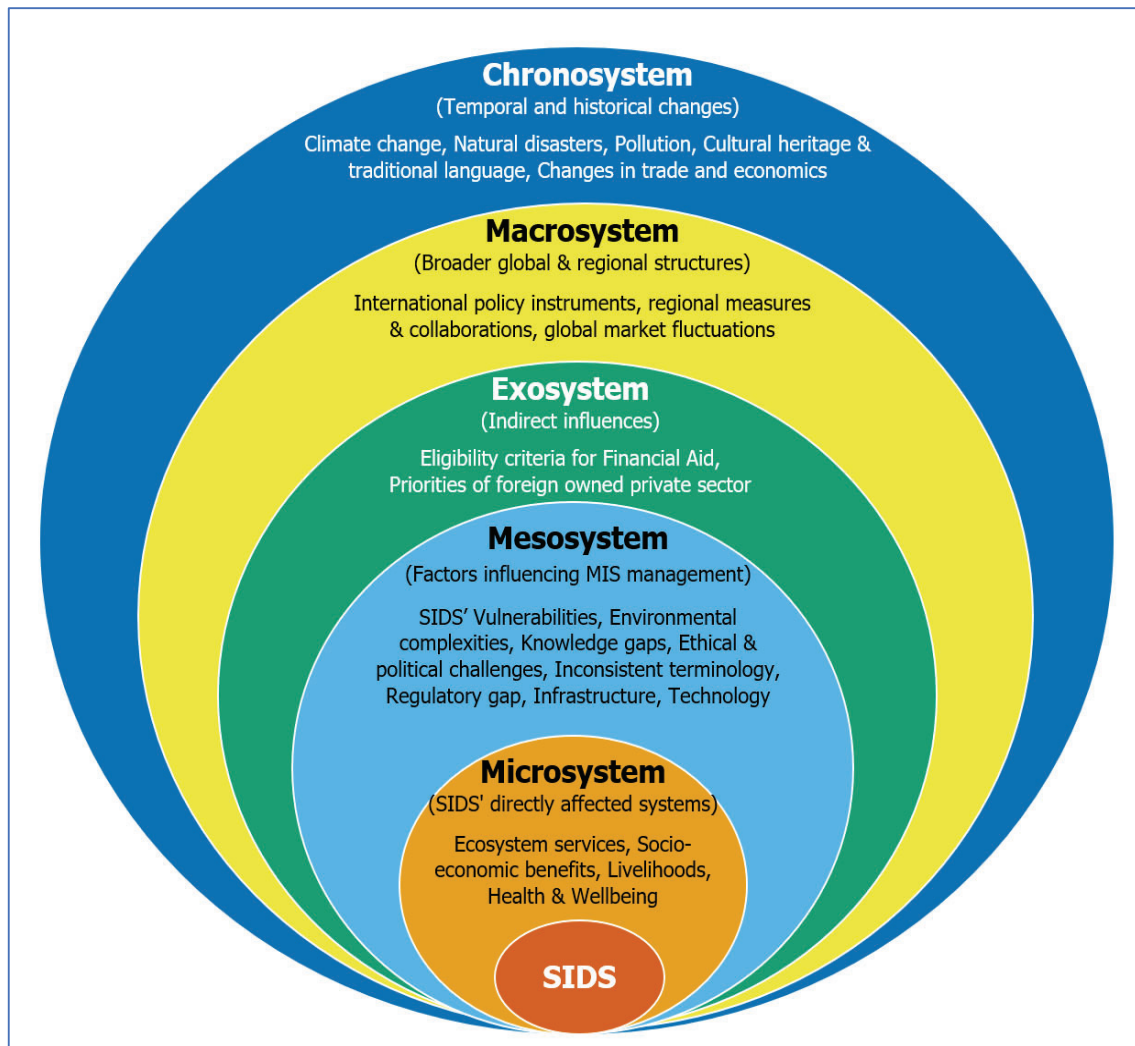


Figure 1.3 Adapted from Bronfenbrenner's Ecological Systems Theory, this model illustrates the multi-level influences on marine invasive species (MIS) management in Small Island Developing States (SIDS). It shows how directly affected systems (Microsystem) interact with internal vulnerabilities and key MIS management challenges (Mesosystem), external factors (Exosystem), broader global and regional systems (Macrosystem), and temporal or historical changes (Chronosystem). Importantly, influence is not only top-down; feedback occurs upward, downward, and across levels, highlighting the dynamic interactions that shape MIS management outcomes.

Within the biosecurity system, pre-border measures are the most cost-effective and preventive form of management for SIDS as they address risks before they reach the national jurisdiction. They reduce reliance on resource-intensive border checks and post-border responses, which are often unrealistic for SIDS given their financial and technical constraints. The necessity of this preventative focus is illustrated by the critical pathway of ship biofouling, where prevention is acknowledged as the most effective risk management strategy for MIS carried via that pathway, because responding to an invasion is often lengthy and costly with eradication being rarely successful (Davidson et al. 2008; Georgiades, Eugene et al. 2020). However, pre-border measures are largely influenced by challenges such as international regulatory frameworks (many of which rely on soft law), voluntary guidance, socio-political dynamics, and increasing pressure from travel, trade and climate change (Bland, L.M. et al. 2024; Edith et al. 2024) which limit the ability of SIDS to enforce precautionary action. Moreover, many environmental conventions require high levels of scientific evidence before intervention (Brasier 2008), disadvantaging SIDS that cannot always generate such data and leaving them exposed to cumulative risks.

For SIDS, the biosecurity systems framework thus provides both an opportunity and a challenge. On one hand, it highlights the importance of integrated measures across all stages of the continuum and on the other, it exposes how resource constraints make border and post-border measures particularly difficult to implement. Therefore, strengthening precautionary, binding pre-border measures represents a fairer and more feasible approach for SIDS, shifting responsibility upstream to the sources of risk rather than downstream to states that are least able to cope with incursions.

1.5 Thesis rationale and structure

The management of marine invasive species is already constrained by multiple interlinked challenges, such as environmental complexities, knowledge gaps, ethical–political considerations, inconsistent terminology, and regulatory gaps amongst others (Chew and Hamilton 2011; Colautti and MacIsaac 2004; Essl et al. 2018; Piria et al. 2021; Seebens et al. 2018; Soto et al. 2024; Tarkan et al. 2024). MIS management is even more challenging for SIDS as it is further compounded by SIDS’ inherent vulnerabilities and reliance on high-risk pathways (World Health Organization 2021) such as ship biofouling, a major and largely underregulated pathway (GEF-UNDP-IMO GloFouling Partnerships 2019a, 2019b, 2025). SIDS’ dependence on shipping for trade, transport, and supply heightens their exposure to hull fouling organisms, which in turn pose significant ecological threats, hold potential to impact livelihoods, and strain already limited resources (Bush 2018; GEF-UNDP-IMO GloFouling Partnerships 2018; Mauritius Attractions 2008-2021). As illustrated in Figure 1.3, which adapts Bronfenbrenner’s bioecological model, these challenges operate at multiple levels, from directly affected systems to broader temporal and global dynamics. The model highlights the complex feedback

between levels that shape the capacity of SIDS to prevent, monitor, and respond to invasions. Addressing these challenges requires a systems-based approach that accounts for the interconnected ecological, social, and governance dimensions of MIS management, and identifies strategies tailored to the unique context of SIDS.

To address this, the thesis adopts the biosecurity systems framework as its conceptual anchor with the overarching aim to investigate the challenges (both internal and external) and needs of SIDS in managing MIS introduced via ship biofouling, and to develop context-appropriate strategies to enhance their capacity for prevention, monitoring, and management. The links between chapters and the levels of the bioecological model are illustrated in Figure 1.4.

The specific objectives are:

- To evaluate the relevance of international policy instruments in addressing all categories of marine invasive species and their introduction pathways, while applying a harmonised analytical framework to help reduce inconsistencies in terminology and reveal regulatory gaps (**Chapter 2**).
- To evaluate the adequacy of these instruments in addressing the three critical management priorities for small island developing states: ecological threats, resource availability, and livelihood implications (**Chapter 3**).
- To assess preparedness of small island developing states to manage the introduction of marine invasive species via ship biofouling, a major and largely unregulated MIS introduction pathway, by documenting existing biofouling management measures and identifying the challenges and needs associated with their implementation (**Chapter 4**).
- To evaluate Australia's biofouling management measures to identify approaches that could be adapted to strengthen biofouling management capacity of SIDS (**Chapter 5**).
- To compare the readiness of a representative SIDS, Mauritius and Australia in managing ship biofouling to reveal structural gaps and explore ways to promote equity and fairness in international policy development (**Chapter 6**).

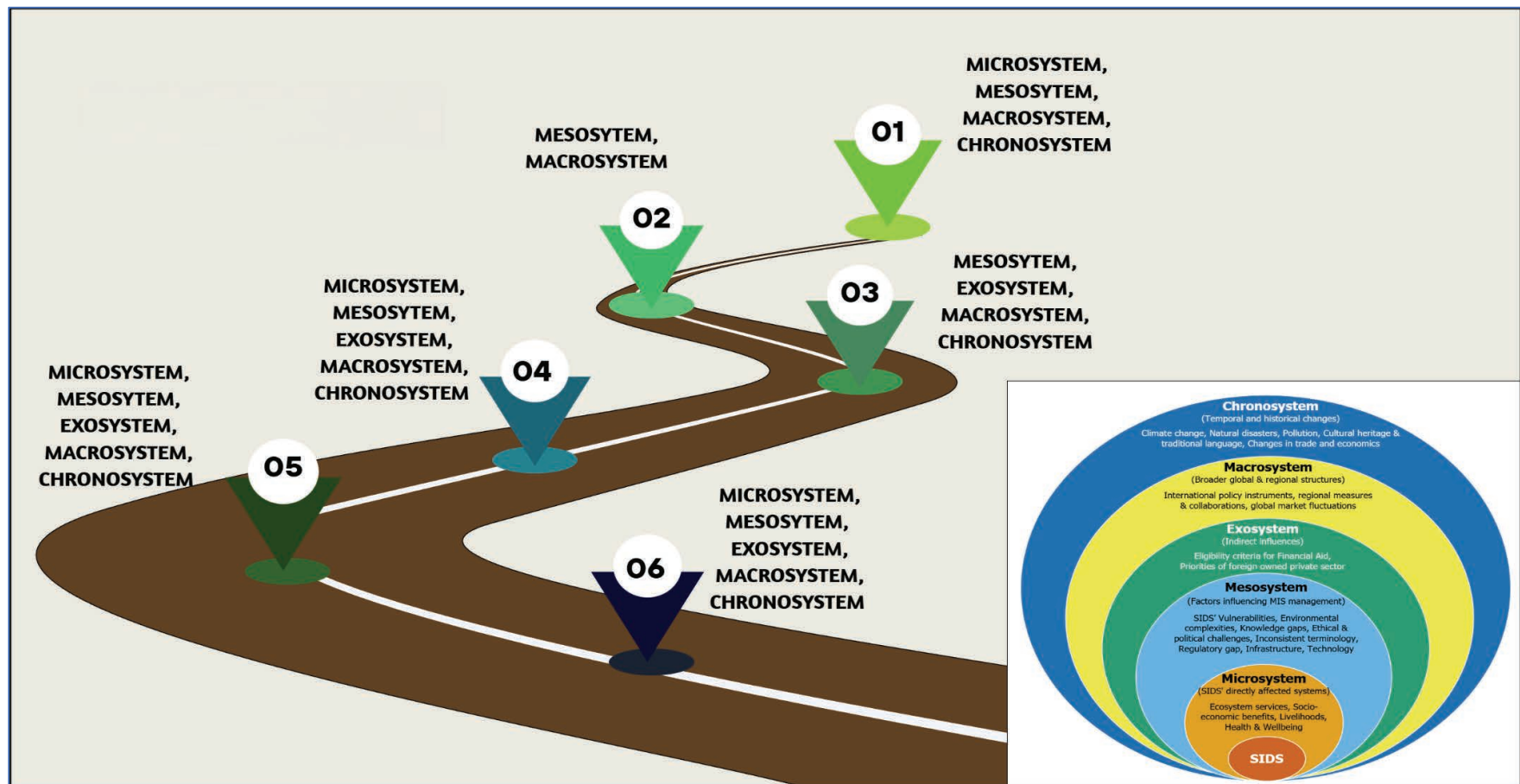


Figure 1.4 Roadmap of the thesis linking chapters to the different levels of Bronfenbrenner's bioecological model. Each level (Microsystem, Mesosystem, Exosystem, Macrosystem, and Chronosystem) is placed along a horizontal axis, with connecting lines indicating the chapters that address challenges at each level. This structure illustrates how the thesis engages with interlinked challenges across scales to strengthen SIDS' capacity to manage marine invasive species introduced via ship biofouling.

In Chapter 2, I addressed the challenges of inconsistent terminology and regulatory gaps, which are major barriers to implementing appropriate marine invasive species management measures. In this chapter, I first consolidated the varied terminology used across the 34 international policy instruments reviewed into five analytical categories: *All Marine Invasive Species*, *Biological Structures*, *Pathogens*, *Animals* and *Plants* to ensure consistency and enable meaningful comparison. Next, I categorised identified introduction pathways into seven key categories: *Shipping*, *Trade*, *Travel & Transportation*, *Release*, *Aquaculture*, *Land-based Activities* and *No Specific Pathway* (for cases where no pathway was mentioned), to assess how well the 34 instruments addressed these introduction pathways. These broader classifications, used to identify relevant international policy instruments, can help inform the development of inclusive management strategies that are adaptable across varied jurisdictions and enhance their practical applicability at a global scale. Additionally, I developed an actionable guidance that strategically matches international instruments with MIS categories and introduction pathways to promote consistency, reduce regulatory gaps, and maximise resource efficiency.

In Chapter 3, I build on the work of Chapter 2 by reviewing the 34 international policy instruments in detail to address the unique vulnerabilities and capacities challenges of small island developing states and regulatory gaps that hinder the effective management of marine invasive species in SIDS. Using a matrix approach, I mapped the 34 international policy instruments against three critical and interconnected management priority criteria: (1) *ecological threats*, (2) *resource availability*, and (3) *livelihood implications*, assessing how well existing measures address these vulnerabilities. I also evaluated the participation of SIDS in binding instruments by compiling a matrix of ratified and enforceable measures relevant to marine invasive species. This chapter highlights the greater importance of binding instruments compared to voluntary ones and underscores the need to consider resource implications when developing international binding measures. It also emphasises that SIDS must be prepared for risks such as ship biofouling, which can be mitigated through pre-border biosecurity measures to anticipate risks and prevent harmful marine invasive species introductions.

In Chapter 4, I assessed the preparedness of small island developing states to manage marine invasive species introductions via ship biofouling, as well as the challenges and needs faced in implementing these measures. I conducted a thematic assessment based on the five dimensions of biosecurity resilience identified by Schneider et al. (2020): being aware, prepared, resourced, responsive, and adaptive. Using a mixed-methods approach, comprising of surveys, interviews, and document analysis, I evaluated preparedness against five criteria: (1) Awareness Level (being aware), (2) Management status (being prepared), (3) Management focus (being adaptive), (4) Challenges and barriers (being resourced, responsive & adaptive) and (5) Needs (being resourced, responsive & adaptive). This Chapter highlights the major challenges that SIDS face in addressing MIS introductions via ship biofouling and identifies their primary needs to inform the development of targeted strategies to close regulatory gaps. It highlights that strengthening legislative and institutional frameworks, building

capacity, improving data collection systems, securing sustainable resources, and enhancing coordination, particularly through stronger pre-border measures will help SIDS develop more integrated, cost-effective, and resilient biosecurity systems. It also underscores the importance of focusing on major introduction pathways rather than on individual species.

In Chapter 5, I evaluated Australia's ship biofouling management measures to identify approaches that could be adapted to strengthen ship biofouling management capacity of SIDS. Using a mixed-methods approach, comprising of surveys, interviews, and document analysis, I reviewed and categorised each strategy into *pre-border*, *border*, and *post-border* measures. Then I documented and evaluated the resources, operational costs and implementation challenges associated with each measure to identify the best approach for managing MIS introduction via ship biofouling that are adapted to needs and challenges of SIDS. This study provides practical recommendations for developing and implementing a resilient biosecurity system, including a proposed vessel-clearance process and biofouling risk-assessment guides. It also emphasises the need for international standards that allow only hull grooming as an in-water cleaning practice, ensuring equity, protecting SIDS' marine environments, and preventing inconsistent practices that could undermine their biosecurity systems.

Lastly, in Chapter 6, I synthesize the systemic gaps, challenges, and capacity constraints identified throughout this thesis and present potential solutions and recommendations to improve preparedness, enhance regional and international cooperation, address SIDS' marine biofouling challenges, promote equity, and strengthen global biosecurity.

2.1 Introduction

2.1.1 Historical underrepresentation and growing recognition of marine invasive species

Biodiversity, livelihoods, health, and leisure activities are threatened globally by marine invasive species (MIS), which have caused increasing financial consequences in recent decades (Cuthbert et al. 2021; Tsirintanis et al. 2022). These impacts are expected to worsen as additional introductions occur (Costello et al. 2025; Cuthbert et al. 2021; Department of Environmental Conservation 2024; World Shipping Council 2021). Despite the growing economic burden and environmental consequences of MIS, research and management efforts have historically lagged behind those addressing terrestrial invasions. While much of the focus on invasive species management has traditionally centred on terrestrial ecosystems, marine environments have received comparatively less attention due to challenges in detecting and monitoring aquatic introductions, compounded by limited knowledge and expertise (Cuthbert et al. 2021; Keller. et al. 2011; Ojaveer et al. 2015; Zitoun et al. 2020). This terrestrial bias is strongly reflected in the scientific literature. For example, the study conducted by Mačić et al. (2018) found that out of 1,149 conservation planning articles, only 10% focused on marine environments, with most studies addressing terrestrial systems. Watkins et al. (2021) further confirmed this pattern, reporting that only 39% of known marine non-indigenous species appear in peer-reviewed literature, and only 9.9% of studies quantified their impacts. These disparities illustrate a substantial gap in knowledge generation for marine biological invasions, limiting the evidence base upon which effective biosecurity frameworks and management strategies depend.

Marine invasive species first gained recognition in 1903 following a mass occurrence of the Asian phytoplankton *Odontella (Biddulphia sinensis)* in the North Sea (International Maritime Organization 2025a). However, it wasn't until the 1970's that detailed assessments of the MIS issue began, and not until the late 1980s that Canada and Australia first raised concerns about MIS at the International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC), the United Nation's body tasked with ensuring environmentally sound shipping (International Maritime Organization 2025a). Although introductions occurred well before the 1970s, global inventories of MIS only became widespread in the later decades of the 20th century, largely due to the absence of systematic monitoring prior to that time (Bailey et al. 2020; GEF-UNDP-IMO GloBallast Partnerships Programme 2017). As a result, many species first recorded between 1965 and 2015 may have been present for decades beforehand, highlighting significant historical gaps in detection and reporting. A

substantial number are believed to have arrived before World War II, with some introductions possibly dating back to the 19th century (Bailey et al. 2020). This historical underreporting is likely explained by a broader lack of scientific capacity, institutional awareness, and coordinated monitoring mechanisms during that period (Figure 2.1).

The development of international policy frameworks addressing MIS in response to these longstanding gaps, has been slow and reactive. It has taken nearly a century after the first detection in 1903 for the first international policy instrument, the voluntary guidelines on ballast water management (1997), to be adopted specifically targeting the MIS issue. Negotiations among the IMO and its member states over the development and ratification of a binding convention took another two decades, with the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) finally adopted and entering into force on 8 September 2017 (Figure 2.1) (GEF-UNDP-IMO GloBallast Partnerships Programme 2017). More recently, growing awareness of ship biofouling as an even more significant vector for MIS has prompted the IMO to issue guidelines for the control and management of ships' biofouling, further expanding international efforts to reduce the spread of MIS via maritime activities (GEF-UNDP-IMO GloFouling Partnerships 2018, 2019d; International Maritime Organization 2025a).

Biological contaminants on traded products, aquaculture and mariculture, fishing gears, marine debris, offshore oil, gas and renewable energy structures, recreational boating, deep-sea mining and research instruments are other potential MIS introduction pathways (Awad et al. 2014; GEF-UNDP-IMO GloFouling Partnerships 2019d; GLOBEFISH 2021; International Maritime Organization 2025b; Lieurance et al. 2023). In recognition of the diverse sources contributing to MIS spread, several international institutions alongside the IMO have developed various conventions, agreements, regulations, protocols and guidelines to prevent and manage MIS introduction. These include the International Union for Conservation of Nature (IUCN), the World Organisation for Animal Health (OIE), the International Trade and Invasive Alien Species (Standards and Trade Development Facility), the Asia Pacific Economic Cooperation forum (APEC) and the Secretariat of the Pacific Region Environment Programme (SPREP).

Regardless of these collaborative efforts, the rate of newly recorded introduced invasive species continues to rise, particularly through accidental pathways and as a consequence of increasing global trade (Sardain, Sardain and Leung 2019; Seebens et al. 2025). This highlights the urgent need for more effective prevention strategies, stronger regulatory enforcement, and enhanced international coordination (Essl et al. 2018). However, the lack of simple, clear, and standardised language between local and global MIS management programs and regulatory gaps addressing this issue remain fundamental barriers to progress. Inconsistent terminology brings a lack of clarity across scientific, policy, and operational contexts and hinders the development and implementation of cohesive and effective management measures (Colautti and MacIsaac 2004; McGeoch et al. 2010; Seebens et al.

2018; Soto et al. 2024; Tarkan et al. 2024). The lack of international policy measures addressing MIS further compound this issue. Given these challenges, a closer look at the terminology used in MIS management and critical pathways managed are essential.

2.1.2 The need for standard terminology

The shifting distributions of MIS, driven by human activities and environmental changes, highlight the critical need for strengthening biosecurity frameworks (Essl et al. 2018; Seebens et al. 2018). However, while there are coordinated international agreements to track and manage certain categories of invasive species such as diseases affecting human, livestock and crops, species that primarily cause environmental damages, have received less regulatory attention. Consequently, efforts to manage environmentally harmful invasive species are often confined to national jurisdictions and are inconsistently applied, with the inaction of some nations undermining the prevention efforts of others (Chew and Hamilton 2011; Keller and Perrings 2011; Piria et al. 2021; Soto et al. 2024; Tarkan et al. 2024). A fundamental challenge in this domain is the absence of standardised terminology.

Fifty-nine terms, including ‘exotic,’ ‘introduced,’ ‘invasive,’ and ‘naturalized,’ among others are frequently used interchangeably, despite their specific ecological definitions (Soto et al. 2024). This lack of terminological consistency impedes effective scientific communication and constrains the development and implementation of robust conservation and management strategies, resulting in substantial ambiguity in translating research into action, leading to wasted resources and secondary ecological impact (Colautti and MacIsaac 2004; Essl et al. 2018; Seebens et al. 2018; Soto et al. 2024; Tarkan et al. 2024). Therefore, to support both scientific understanding and effective policymaking, standardised terminology for addressing MIS must be developed, together with a clear understanding of species introduction pathways to guide effective mitigation strategies. Such terminology should be grounded in biogeographic, evolutionary, ecological, and ethical principles (Essl et al. 2018; Seebens et al. 2018; Soto et al. 2024; Tarkan et al. 2024). The following section outlines the central role of introduction pathways in shaping effective mitigation strategies and setting the foundation for policy alignment and action.

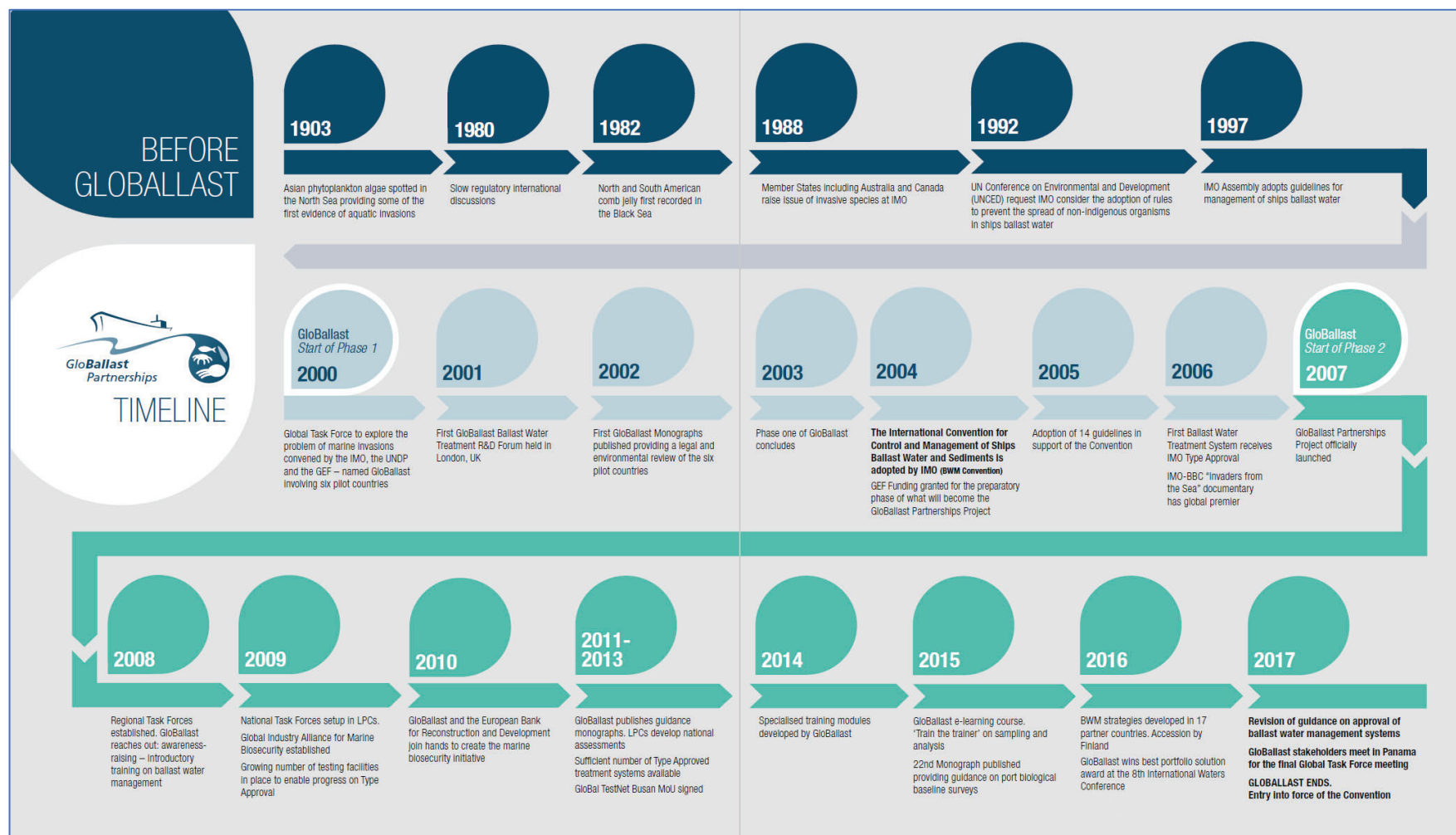


Figure 2.1 Timeline showing the lengthy process involved in the development of the Ballast Water Management Convention, from identification of problem in 1903 to the entry into force of the convention in 2017 (GEF-UNDP-IMO GloBallast Partnerships Programme 2017).

2.1.3 The critical role of introduction pathways

“Transport–stowaway” pathways such as hull fouling, ballast water, hitchhikers on vessels, and contaminated angling or fishing gear are associated with the highest number of introduced taxa. Shipping, in particular, stands out as the single most significant contributor to the global spread of MIS through hull fouling and ballast water discharge (Figure 2.2) (Awad et al. 2014; GEF-UNDP-IMO GloFouling Partnerships 2018; GLOBEFISH 2021; International Maritime Organization 2025b; Lieurance et al. 2023). Ships transport eighty percent of the global trade among countries, with some 35,000 vessels presently involved (De Poorter, Darby and MacKay ; GEF-UNDP-IMO GloBallast Partnerships Programme 2017). Estimates indicate that approximately 7,000 species are transferred around the world in ballast water every hour (~ 61 million species/year) (GEF-UNDP-IMO GloBallast Partnerships Programme 2017).

Both “transport–contaminant” and “transport–stowaway” pathways are closely tied to global trade, with the “transport–stowaway” pathway responsible for introducing the highest number of marine taxa (Figure 2.2) (Lieurance et al. 2023). As international trade and shipping activities continue to grow, so will the global spread of MIS because the combined effects of maritime trade expansion, global connectivity, and aquaculture development are diversifying the pathways through which MIS are introduced and dispersed (GEF-UNDP-IMO GloFouling Partnerships 2019d). While certain introduction pathways, such as ballast water, are formally regulated under instruments like the International Convention for the Control and Management of Ships’ Ballast Water and Sediments (2004), other pathways including hull fouling, aquaculture, marine debris, and recreational boating remain inconsistently addressed or entirely unregulated across international instruments (GEF-UNDP-IMO GloFouling Partnerships 2019d; Sardain, Sardain and Leung 2019).

These pathways operate across overlapping jurisdictions and management regimes and despite decades of research and policy development, the management of MIS continues to be hindered by two interrelated challenges: (1) the inconsistent terminology across international instruments and (2) gaps or mismatches in the coverage of major introduction pathways. These challenges limit the effectiveness of global governance frameworks, complicate cross-jurisdictional coordination, and undermine operational responses to MIS (Colautti and MacIsaac 2004; Essl et al. 2018; GEF-UNDP-IMO GloBallast Partnerships Programme 2017; Keller and Perrings 2011; Seebens et al. 2018; Soto et al. 2024; Tarkan et al. 2024).

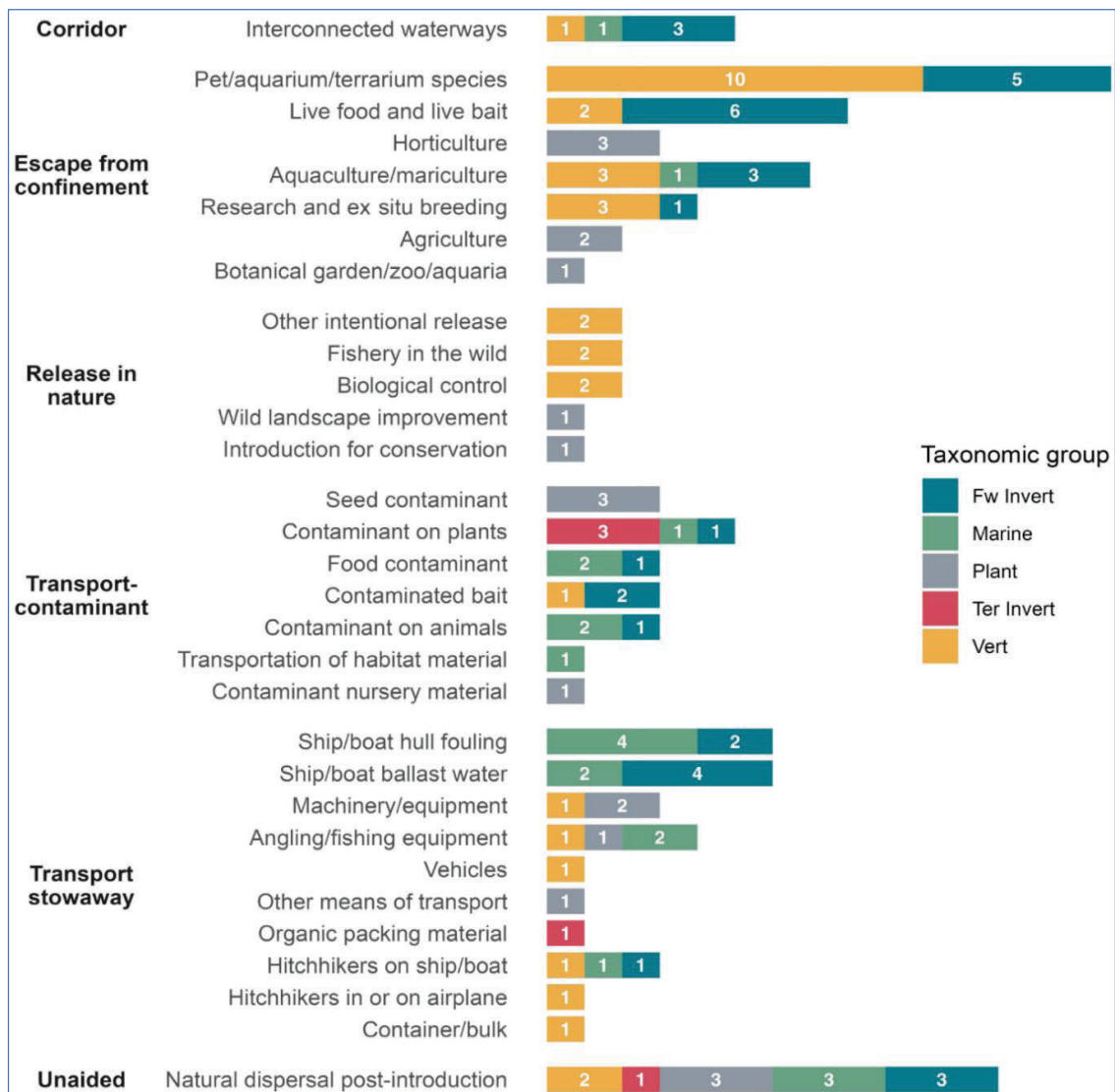


Figure 2.2 Subcategory pathways of the very high and high-risk taxa. The number of taxa classified very high and high risk for arrival through pathway subcategories (Convention on Biological Diversity level 2) for introduction. Numbers in boxes indicate the number of taxa associated with the pathway. Pathway hierarchy is based on categories outlined by the Convention on Biological Diversity (2014) and Harrower et al. (2018). Fw Invert, freshwater invertebrates; Ter Invert, terrestrial invertebrates; Vert, vertebrates (Lieurance et al. 2023).

2.1.4 Managing marine invasive species

The combination of fragmented pathway coverage by international policy instruments and inconsistent terminology has significant implications for global MIS management (Sardain, Sardain and Leung 2019; Soto et al. 2024). Gaps in pathway regulation allow high-risk vectors to escape control, facilitating unintended introductions and secondary dispersal events, while terminological ambiguity undermines coordination between jurisdictions, complicating assessment, monitoring, and reporting of invasions (Colautti and MacIsaac 2004; Essl et al. 2018; GEF-UNDP-IMO GloFouling Partnerships 2019c). These challenges are particularly acute in marine environments, where the physical and ecological complexity of oceans, combined with limited monitoring capacity, hinders early detection and rapid response (Bailey et al. 2020; Cuthbert et al. 2021; Ojaveer et al. 2015). As international capacity to manage marine biological invasions falls behind the pace of modern global trade and travel, marine systems remain vulnerable, with MIS often becoming well-established and widespread before they are detected (Bailey et al. 2020; Keller. et al. 2011).

Given the sheer diversity of lifecycles, modes of dispersal and modes of transport in operation there may be a mismatch between MIS ecology and existing management policy instruments. Without improved international cooperation and harmonised preventive measures, that addresses inconsistent terminology and limited pathway coverage, the rate of MIS introductions is expected to rise, especially as trade liberalisation continues to lower barriers to the global movement of goods and vessels (Keller. et al. 2011). The development of binding international measures remains slow, highlighting the urgent need for coordinated action.

To address the key barriers that hinder effective MIS management, namely (1) the lack of focus of international efforts on marine invasive species, (2) the lack of standardised terminology that results in inconsistent definitions and management approaches, and (3) the insufficient regulation of critical introduction pathways, this policy review aimed to answer the question: ***“To what extent are international policy instruments relevant in addressing different categories of marine invasive species and their various introduction pathways?”***. This study identified, assessed, and evaluated relevant international policy instruments, specifically examining whether these measures comprehensively cover all categories of MIS and their introduction pathways. The review included both academic research (published between 2019 and 2024) and grey literature to ensure broad coverage and to capture the most recent management measures.

2.2 Methods

This review was conducted in two stages. Stage one, a systematic search for relevant publications that focus on international policy instruments (conventions, guides and protocols) addressing MIS and the second stage consisted of reviewing identified international policy instruments studied in those publications.

2.2.1 *Systematic search and study selection*

2.2.1.1 Literature search and eligibility criteria

The systematic search and study selection followed steps 2-6 from the guide by Kazi et al. (2021) for conducting a systematic scoping review. To address the research question and avoid confusion, a set of inclusion and exclusion criteria was first established (Table B1). Following which an initial limited search on the topic was conducted to formulate and finalise the relevant keywords (Table B2) for the literature search and identify suitable databases.

The search strategy focused on literature related to international policy instruments addressing marine invasive species, conducted (February 2025) across the Web of Science (WoS), SCOPUS, James Cook University Library databases, Google Scholar and Google search engine, using the search strings and synonyms listed in Table B2. After searching these sources, the inclusion and exclusion criteria (Table B3) were applied to refine the results before downloading. Given that each database uses different subject headings, synonyms (Table B3) were employed to match categories across databases. For grey literature retrieved from Google, only the subject area was used to filter out irrelevant results.

2.2.1.2 Study selection through two-step screening

The systematic search identified 238 publications, including peer-reviewed articles, survey reports, technical reports, conventions, laws, regulations, PhD theses, and flyers, which were imported into Endnote version 20.01. These studies underwent a two-step screening process (Figure 2.3) by a single reviewer, B. Komul Kalidin. First, the titles and abstracts of the 238 publications were reviewed. Eighty-seven publications that met the inclusion criteria (Table B1) were retained, while 151 were excluded. In the second step, a full-text review was conducted on the 87 retained publications, resulting in 78 relevant publications.

2.2.1.3 Data extraction, charting and synthesis

Microsoft Excel was used to extract and record the following information collected from the 78 publications: author(s), year of publication, and the names of the policy instrument(s) evaluated (See the Supplementary Information Excel workbook, Sheet “Publication Reviewed”). A total of 91 policy instruments (conventions, protocols, and guidelines) were documented (See the Supplementary Information Excel workbook, Sheet “Policy instruments identified.”). To reduce individual-level bias during data extraction and synthesis, the process and findings were reviewed and discussed with my advisory panel, whose input helped validate the categorisation and ensure consistency and rigour in the interpretation of the data.

2.2.2 *International policy instrument review*

2.2.2.1 Policy instrument selection

The 91 policy instruments were further screened and 38 regional instruments were excluded since these were either region-specific in their application or derived from major international policy frameworks such as the United Nations Convention on the Law of the Sea (UNCLOS), Convention on Biological Diversity (CBD), Food and Agriculture Organization (FAO) treaties and guides, International Plant Protection Convention (IPPC), United Nations Environment Programme (UNEP), World Trade Organization (WTO) Agreements, Sanitary and Phytosanitary Agreement (SPS), World Organisation for Animal Health (OIE)’s guides and standards, Convention on Migratory Species (CMS), Convention on International Trade in Endangered Species (CITES), International Maritime Organization’s conventions, among others.

The remaining 53 international policy instruments were further reviewed, with duplicates (i.e., instruments listed under different names) removed. Where multiple versions existed, the most recent or amended version was identified and included. Since international conventions are not updated on a regular or predictable basis, no fixed timeframe was applied; instead, the most current publicly available version of each instrument was used. Ultimately, 38 international policy instruments were selected, searched online, and their available documents were downloaded. Documents relating to marine ecosystems, marine biodiversity, or the management of invasive species in oceanic environments as well as general instruments applicable to MIS were included, while documents related to terrestrial ecosystems, land-based invasive species, or non-marine biosecurity protocols were excluded, leaving 34 documents for further analysis. Table B4 provides a summary of the documents identified, excluded, and the reasons for their inclusion or exclusion.

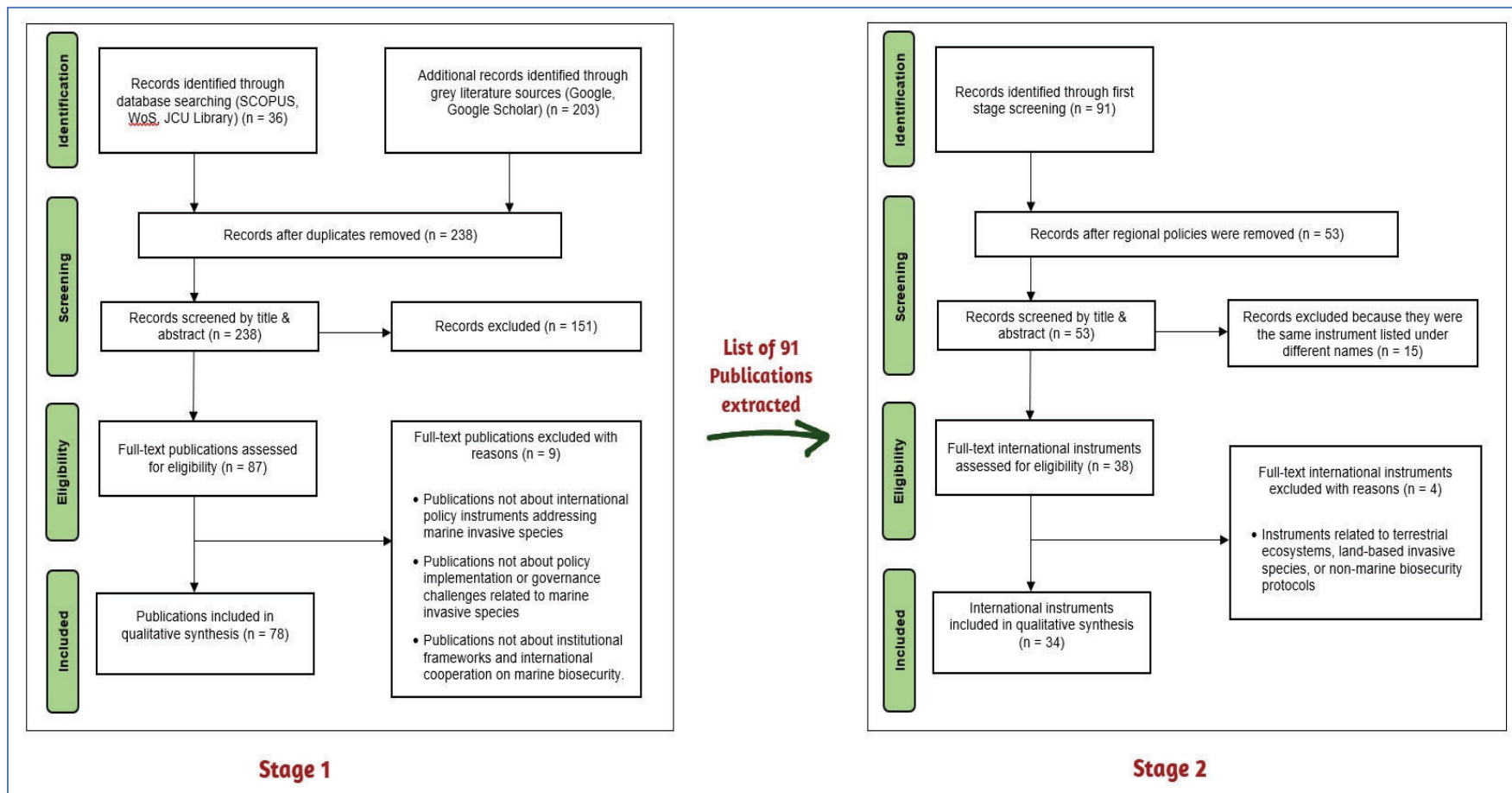


Figure 2.3 Literature search and selection schematic flow diagram. Format taken from Kazi et al. (2021).

2.2.2.2 Data extraction, charting and synthesis

To assess the relevance of the 34 international policy instruments in addressing marine invasive species and their introduction pathways, a detailed textual analysis was conducted. The analysis focused on reviewing, recording and categorising the terminology used to define invasive species, the introduction pathways addressed, the type of introductions, the nature of implemented measures and their scope (Table B4). All relevant data were extracted and recorded using Microsoft Excel, and the categorisation of terminology, introduction pathways, types of introductions, and policy measures are summarised in Table 2.1.

The terminology used across the 34 international policy instruments varied remarkably, ranging from specific references such as *pathogens*, *parasites*, or *genetically modified organisms* to broader terms like *pests*, *alien species*, or *aquatic invasive species* (Table B4). In many cases, the instruments did not specify particular taxa, instead contained general descriptors or risk-based language (e.g., *disease-causing organisms* or *hazards*). Therefore, to ensure consistency and enable meaningful comparison while also recognising that not all countries have equal access to taxonomic expertise or monitoring capacity, I consolidated these terms into five analytical categories: **All Marine Invasive Species**, **Biological Structures**, **Pathogens**, **Animals** and **Plants**. This broader classification supports the identification of potential coverage gaps and facilitates the development of inclusive management strategies that are adaptable across varied jurisdictions. Although this approach may reduce taxonomic precision, it enhances the practical applicability and policy relevance of the findings at a global scale.

Similarly, to assess how well the 34 instruments address these pathways, I categorised them according to their functional focus. The key pathway categories identified in my review include **Shipping, Trade, Travel & Transportation**, **Release**, **Aquaculture**, and **Land-based Activities**. An additional category, **No Specific Pathway**, was used to group instruments that did not explicitly mention any introduction pathway (see Appendix 4). This categorisation approach was crucial for ensuring consistent terminology and enabling clearer comparisons across the instruments. For a detailed summary of these categories and their descriptions, refer to Table B4 and Table 2.1.

Table 2.1 *Categorisation of terminology, introduction pathways, and policy measures.*

Component	Category	Description / Examples
Terminology	<i>All Marine Invasive Species</i>	Harmful aquatic organisms, invasive aquatic species, pests, biofouling, introduced exotic species, exotic species, foreign species, alien species, invasive alien species, new species, non-indigenous organisms, non-native species, plant/animal/microbial or other origin, and animal or plant life. This category comprises all organisms including those classified under “Biological Structures”, “Pathogens”, “Animals”, and “Plants”.
	<i>Biological Structures</i>	sewage, garbage, waste, living modified organisms, genetically modified organisms, genetically altered stocks, genetic material, viruses, and viroids.
	<i>Pathogens</i>	pathogens, pathogenic agents, infectious agents, diseases, disease agents, and parasites.
	<i>Animals</i>	Specific references to animal species
	<i>Plants</i>	Specific references to plant species
Introduction Pathways	<i>Shipping</i>	Ballast water, hull fouling, stowaways, sewage, garbage, waste
	<i>Trade</i>	Intentional: agriculture, aquaculture, live food, live bait, pets/aquariums/terrariums, etc. Unintentional: contaminants on plants/animals, food contaminants etc.
	<i>Travel & Transportation</i>	Hitchhikers in/on planes and vessels, tourists, packaging materials etc.
	<i>Release</i>	Intentional: fisheries. Unintentional: pets/aquariums
	<i>Aquaculture</i>	Species introduced for aquaculture purposes
	<i>Land-based activities</i>	Introduction via contamination from soil, agricultural activities, landscaping, etc.
	<i>No Specific Pathway</i>	Cases where no introduction pathway was mentioned or identified

Type of Introduction	<i>Primary</i>	First introduction of a non-indigenous species to a new region.
	<i>Secondary</i>	Spread of already introduced non-indigenous species within local areas.
Nature of Measures	<i>Preventive</i>	Actions taken before an introduction occurs to reduce the risk of invasive species
	<i>Corrective</i>	Actions taken after introduction to manage, control, or eradicate invasive species
Scope of Measures	<i>General</i>	Broad measures that apply across multiple species, pathways, or sectors
	<i>Specific</i>	Targeted measures focused on species/category of species, pathways, or locations

2.3 Results and discussion

2.3.1 Terminology analysis

Across the 34 instruments reviewed, the terms *invasive alien species* and related terminology such as *non-native species*, *exotic species*, *new species*, *non-indigenous species*, *foreign species*, *pests*, *animals* and *plants* appeared frequently, indicating general relevance to both terrestrial and aquatic environments. Terms related to health risks, including *pathogens*, *diseases*, *viruses* and *parasites*, were also common, reflecting concerns linked to international trade, travel and transportation. In contrast, terminology more specific to MIS such as *harmful aquatic organisms*, *invasive aquatic species* and *biofouling* was less frequently used. Based on both the terminology and the scope of these instruments, 20 were assessed as directly relevant to marine invasive species, while 14 were indirectly relevant (Table B4).

To address this policy chaos analytically and ensure that existing instruments, even those with indirect relevance can be strategically leveraged to address the under-prioritised MIS issue, this study employed a pragmatic approach: consolidating the varied terminology found across the instruments into five functional analytical categories (*All Marine Invasive Species*, *Biological Structures*, *Pathogens*, *Animals*, and *Plants*). This categorisation was necessary to ensure consistency and enable meaningful comparison across the instruments reviewed, acknowledging that resource-limited jurisdictions like SIDS often lack the taxonomic expertise or capacity required by highly specific definitions.

Analysis of instruments by MIS category revealed a pattern of broad applicability rather than specific focus. Twenty-two instruments were found to be relevant to the encompassing *All Marine Invasive Species* category, while the *Biological Structures* category was addressed by 13 instruments, *Pathogens* by 14, *Animals* by 11, and *Plants* by four (Table 2.2). A significant pattern that emerged was that most policy instruments addressed multiple overlapping categories of MIS, with only a few instruments specific to a single category, such as *Pathogens* (1 instrument) and *Biological Structures* (3 instruments). For instance, 12 of the 22 instruments relevant to *All Marine Invasive Species* also covered one or more additional categories. Similarly, all instruments addressing *Animals* and *Plants* overlapped with at least one other category.

These findings highlight that, while many instruments are relevant to all categories of MIS, relatively few are tailored exclusively to particular functional groups. The wide range of terms identified in this study underscores the ongoing problem of inconsistent and ambiguous terminology in invasion biology, a finding that aligns with Soto et al. (2024). This study also shows that the challenge is compounded by the limited tailoring of international policy instruments to MIS, which have historically received less research and management attention than terrestrial invasions. (Cuthbert et al. 2021; Keller. et al. 2011; Ojaveer et al. 2015; Zitoun et al. 2020). The prioritisation of broader environmental or trade goals by

existing conventions, together with the variation in terminology used across international instruments to address invasive species, reflects an insufficient focus on marine invasive species and a lack of terminology standardisation (Table B4). As these instruments often shape policy and practice, such variation may perpetuate terminological inconsistency, thereby hindering effective science communication and policymaking. This, in turn, undermines the effective conservation of indigenous species as well as the management of non-indigenous species. These observations are consistent with previous studies (Colautti and MacIsaac 2004; Essl et al. 2018; Soto et al. 2024), which showed that a lack of clear and consistent definitions can lead policymakers to delay action or adopt ineffective management strategies, resulting in wasted resources and unintended ecological consequences.

Ultimately, these findings underscore the urgent necessity for the global community to adopt universal, clear, and consistent terminology that effectively support both scientific understanding and robust policymaking moving forward (Essl et al. 2018; Seebens et al. 2018; Soto et al. 2024; Tarkan et al. 2024).

2.3.2 Introduction pathway analysis

McNeely et al. (2001) argue that every introduced species should be regarded as potentially invasive until clear evidence proves otherwise. However, gathering this evidence often requires significant time and resources, which many countries lack. This underscores the importance of addressing the introduction pathways early on, as doing so can save time and money while preventing consequential impacts. Taking proactive measures against marine invasive species is essential for minimising long-term ecological and socio-economic risks (Lieurance et al. 2023).

In line with this perspective, this review assessed the relevance of international policy instruments in addressing key introduction pathways. Lieurance et al. (2023) identified shipping (e.g., ballast water, ship biofouling, hitchhikers on vessels, and contaminated angling or fishing gear), trade (e.g., unintentional release from the pet/aquarium trade, live food, and live bait, contaminant on plants/animals and food contaminants), and aquaculture as common arrival pathways for introduced aquatic species. Among these, the “transport-stowaway” pathway associated with shipping was identified as the most frequent route for marine species introductions (Figure 2.2).

This assessment of how well the 34 international policy instruments address these pathways revealed that Trade is targeted by the highest number of instruments (14), followed by Shipping (11), Aquaculture (8), Travel and Transportation (6), and Release (4). Only one instrument address land-based activities, while four do not address any specific pathway (see Table 2.2).

Furthermore, this review evaluated instruments addressing different categories of MIS introduced through various pathways. The findings show that most international policy instruments are broadly relevant to address all categories of MIS introduced via the major key pathways of *Shipping, Trade, and Aquaculture* (Table 2.2). This indicates that the full range of MIS introduced through these critical pathways is being addressed at the international level.

The analysis of the instruments was also extended to the type, nature, and scope of measures they propose. Seventeen instruments primarily focus on primary introductions, while another 17 address both primary and secondary introductions. Nineteen instruments emphasise preventive measures aimed at reducing the risk of species introduction, while 15 include both preventive and corrective measures, such as mitigation or response actions once an introduction has occurred. The specificity of the measures also varies, with 16 instruments outlining general obligations or guiding principles, and 18 providing more specific, targeted actions (Table B4).

The observed overlap of instruments addressing multiple MIS category and introduction pathways (see Table 2.2), along with the variety of measures identified, highlights the potential relevance of these instruments in supporting a broad and flexible approach to managing MIS. These findings further suggest that internationally available response strategies are generally well-aligned with key introduction pathways, highlighting their relevance for global marine biosecurity efforts.

2.3.3 Limitations in international policy instruments

Despite the existence of various international policy instruments with potential to support marine biosecurity, significant limitations undermine their overall effectiveness (Table B5). A significant proportion of instruments address MIS only indirectly, with their primary focus on broader objectives such as trade, pollution, or maritime safety. In addition, many instruments have limited scope and coverage, often lacking specific provisions or actionable measures for the management of MIS. A further constraint is that several guidelines and frameworks are voluntary in nature and therefore lack enforceability. These limitations pose challenges to the effective management of MIS. Strengthening these frameworks is therefore essential to enhance the resilience of vulnerable marine ecosystems and ensure more robust biosecurity measures. At the same time, the findings indicate that the overlap and diversity of existing instruments offer a valuable foundation for a broad and flexible response, highlighting the importance of leveraging and adapting these tools to strengthen global efforts against MIS.

Table 2.2 *International policy instruments relevant to addressing marine invasive species categories and introduction pathways*

International Policy Instrument	MIS Categories	Introduction Pathways
Convention on the Facilitation of International Maritime Traffic (FAL) as amended 1965	All Marine Invasive Species, Pathogens	Trade
Convention on International Trade in Endangered Species (CITES) 1973	Animals, Plants	Trade
International Convention for Safety of Life at Sea (SOLAS) as amended including the ISM Code 1974	All Marine Invasive Species	Shipping
Convention on the Conservation of Migratory Species of Wild Animals (CMS) 1979	Animals	No Specific Pathway
United Nations Convention on the Law of the Sea (UNCLOS) 1982	All Marine Invasive Species	No Specific Pathway
MARPOL 73/78, Annex IV 2003 & Annex V 1988	Biological Structures	Shipping
Convention on Biological Diversity (CBD) 1992	All Marine Invasive Species, Biological Structures	Trade, Release
Rio Declaration and Agenda 21 1992	All Marine Invasive Species	Shipping, Trade
General Agreement on Tariffs and Trade (GATT) 1994	Animals, Plants	Trade
WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) 1995	All Marine Invasive Species, Pathogens	Trade
FAO Code of Conduct for Responsible Fisheries and subsequent Technical Guidelines 1995	All Marine Invasive Species, Biological Structures	Aquaculture

UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities 1995	All Marine Invasive Species	Land-based Activities
Agreement for the Implementation of the Provisions of UNCLOS relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) 1995	Biological Structures, Animals	Shipping
London Convention 1972 & London Convention Protocol 1996	Biological Structures	Shipping
FAO guidelines on Precautionary Approach to Capture Fisheries (Including Species Introductions) 1996	All Marine Invasive Species, Biological Structures, Pathogens	Aquaculture
Convention on the Law of Non-navigational Uses of International Watercourses 1997	All Marine Invasive Species	No Specific Pathway
International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) and the Seafarer's Training, Certification and Watchkeeping Code (STCW Code) 1978/95/97	All Marine Invasive Species	Shipping
Convention on International Civil Aviation (Resolution A-32-9 Preventing the Introduction of Invasive Alien Species) 1998	All Marine Invasive Species	Travel & Transportation
IUCN Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species 2000	All Marine Invasive Species, Biological Structures	Trade, Travel & Transportation, Release, Aquaculture
Cartagena Protocol on Biosafety 2000	Biological Structures	Trade, Travel & Transportation, Release

The Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2001	All Marine Invasive Species, Biological Structures, Pathogens, Animals, Plants	No Specific Pathway
International Convention on the Control of Harmful Anti-fouling Systems on Ships (Anti-Fouling Convention) 2001	All Marine Invasive Species	Shipping
RAMSAR (Resolution VIII.18 Invasive species and wetlands) 2002	All Marine Invasive Species	Trade
Codex Alimentarius (Code of Practice for Fish and Fishery Products) 2003	Biological Structures, Pathogens, Animals	Trade, Aquaculture
International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004	All Marine Invasive Species, Pathogens	Shipping
ICES Code of Practice on the Introduction and Transfer of Marine Organisms 2005	All Marine Invasive Species, Biological Structures, Pathogens	Trade, Travel & Transportation, Release, Aquaculture
International Health Regulations (IHR) and plant and animal health agreements 2005	Pathogens	Trade, Travel & Transportation
FAO guide: Aquaculture development. 2. Health management for responsible movement of live aquatic animals. 2007	All Marine Invasive Species, Biological Structures, Pathogens, Animals	Aquaculture
FAO guide: Aquaculture development. 6. Use of wild fishery resources for capture-based aquaculture. 2011	Biological Structures, Pathogens, Animals	Aquaculture

World Organisation for Animal Health (OIE)'s Guidelines for assessing the risk of non-native animals becoming invasive. 2012	All Marine Invasive Species, Pathogens, Animals	Shipping, Trade, Travel & Transportation
IMO Guidance for Minimizing the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft 2012	All Marine Invasive Species	Shipping
IMO Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species 2023	All Marine Invasive Species, Pathogens, Animals, Plants	Shipping
Manual of Diagnostic Tests for Aquatic Animals 2024	Biological Structures, Pathogens	Trade
The Aquatic Animal Health Code 2024	Pathogens, Animals	Aquaculture

2.3.4 Leveraging existing policy instruments to address MIS

Addressing the growing threat of marine invasive species to global marine ecosystems requires preventive strategies that target all categories of MIS and their introduction pathways. This policy review aimed to answer the research question: ***“To what extent are international policy instruments relevant in addressing different categories of marine invasive species and their various introduction pathways?”***. This study examined the relevance of international policy instruments in managing MIS across various introduction pathways. The findings showed that while numerous international policy instruments can be applied to MIS, gaps in scope, coverage and relevance reduce their overall effectiveness. To address these gaps, this study identified the following areas for further research:

1. The key pathways addressed in the literature are *Shipping*, through ballast water, sewage and waste, and hull fouling, *Trade* and *Aquaculture*. Many instruments prioritise broader environmental or trade goals over direct MIS management, limiting their effectiveness in addressing biosecurity risks specific to MIS.
2. A risk-based approach that prioritises pathways based on their risk levels and historical MIS data would enable more efficient resource allocation and impactful regulation. Additionally, with emerging pathways and shifting environmental conditions, adaptive strategies that respond swiftly to new evidence or threats could strengthen global MIS control.
3. Closing these regulatory gaps is vital for a resilient global framework against marine invasive species. While many international policy instruments are indirectly relevant and lack comprehensive MIS specific measures, their broad applicability to critical introduction pathways presents an opportunity to leverage existing frameworks to better safeguard marine ecosystems and resources.
4. A pathway-focused approach offers a more cost-effective and practical solution than targeting individual species (Ojaveer et al. 2015). By integrating this approach into international efforts, regulatory frameworks can be strengthened to address the diverse range of MIS introduced through these pathways.

Detection capacity for invasive species varies widely across the globe, with underreporting more common in less developed countries and higher detection rates in nations with stronger research capabilities (McGeoch et al. 2010). These global disparities, along with scientific uncertainties, complex ecological factors, lack of clear and standardised terminology, and uneven management efforts confined to national borders, underscore the challenges of effectively addressing MIS. This highlights

the need for strong international frameworks and precautionary approaches that go beyond national-level monitoring.

International regulations form the foundation of global biosecurity, serving as a primary safeguard against invasive species and diseases (Bland, Lucie M. et al. 2024), and are essential for preventing biosecurity risks before they reach the border. The implementation of these regulations is operationalised through a series of coordinated activities across the biosecurity continuum. The biosecurity system comprises three interconnected components: pre-border, border, and post-border which together encompass seven main activities that collectively manage biosecurity risks (Bland, Lucie M. et al. 2024; Schneider, K. and Arndt. 2020). The pre-border component includes (1) *Anticipating biosecurity risk*; (2) *Preventing biosecurity risk material arriving at the border*. The border component involves (3) *Screening entry pathways to detect non-compliance*. The post-border component covers (4) *Detecting non-native species and disease incursions or outbreaks in the country*; (5) *Preparing for an incursion or outbreak of non-native species and diseases*; (6) *Responding to an incursion or outbreak of non-native species and diseases*; and (7) *Recovering from an incursion or outbreak and adapting to new circumstances* (Bland, Lucie M. et al. 2024).

Pre-border measures, guided by international policy instruments, are the most cost-effective approach as they aim to prevent species introductions before they occur. In contrast, border and post-border responses, which are usually managed at national and local levels (see Table 2.1 and Figure 2.1 from Bland, Lucie M. et al. (2024)) require more resources (see Figure ES 2 from Schneider, K. and Arndt. (2020)). This review supports the preventive, pre-border component of the biosecurity system by identifying how existing international policy instruments can be strategically applied to MIS. I also propose practical guidance (Figure 2.4) in this study for matching the appropriate policy instrument(s) to each category of MIS and their pathways, with a focus on early detection and action. This approach strengthens the pre-border component, which remains the most effective line of biosecurity defence.

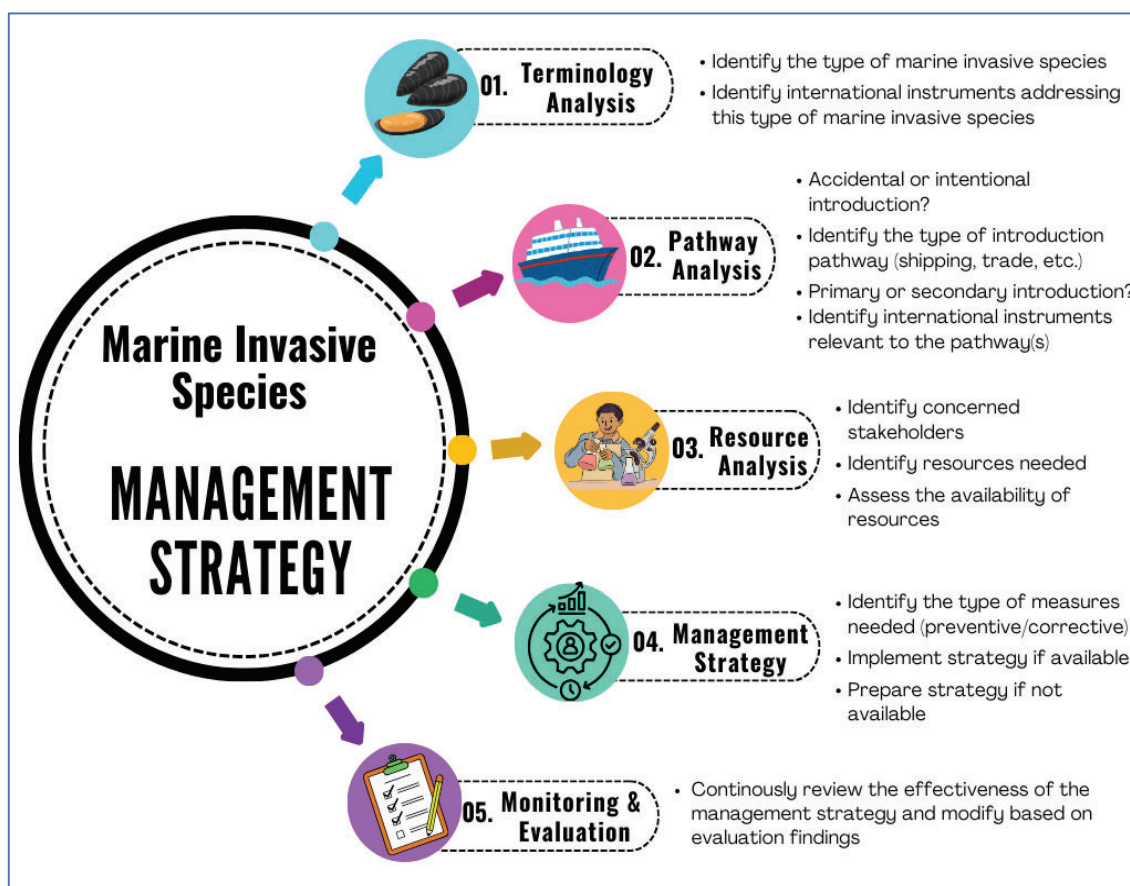


Figure 2.4 Guidance for Strategic Management of Marine Invasive Species. This guide allows flexibility, enabling each component to be revisited or refined as needed, depending on the specific requirements of the type of invasive species and/ or introduction pathway management context.

The guidance consists of five interconnected components, each with specific goals and activities:

- **Terminology Analysis**

This step is appropriate when a specific MIS has been identified. It involves classifying the species into one or more of five functional categories: *All Marine Invasive Species*, *Biological Structures*, *Pathogens*, *Animals*, and *Plants*. This helps identify which international policy instruments apply to the species and its introduction pathway(s), as well as the key stakeholders involved. For example, the Zebra Mussel (*Dreissena polymorpha*) falls under the categories *Animals* and *All Marine Invasive Species*, so policy instruments addressing these categories would be relevant for managing it. Table 2.2 can be used to find which international policy instruments is more relevant to address each category of MIS, as well as the species' introduction pathway. This will guide the selection of preventive or corrective actions most appropriate for a given species.

- **Pathway Analysis**

This step is used when no specific MIS has been identified. It focuses on understanding how MIS might be introduced and groups these pathways into key categories: *Shipping, Trade, Travel and Transportation, Release, Aquaculture, and Land-based Activities*. The analysis helps identify whether introductions are intentional or accidental, and whether they are new (primary) or spread from existing locations (secondary). It also points to the relevant international policy instruments that can be used to manage each pathway and identifies the key stakeholders involved. Table 2.2 can be used as a reference to identify which international policy instruments are most relevant for addressing each pathway and guiding the selection of preventive or corrective measures.

- **Resource Analysis**

This component identifies the stakeholders and operational resources needed, such as personnel, technology, and regulatory frameworks to effectively anticipate and prevent MIS from crossing national borders. It builds on the insights from Pathway Analysis and Terminology Analysis, which identify the relevant introduction routes, species categories, and corresponding international policy instruments. These instruments help with defining the type and scope of preventive measures needed, informing what resources are required, who should be involved, and where efforts should be focused. The analysis then maps out the roles of government agencies, port authorities, and industry actors, and assesses the availability of personnel, funding, technology, and expertise. The goal is to ensure that preventive actions can be implemented efficiently and that critical resources are in place before risk materialises.

- **Management Strategy**

Building on insights from Pathway Analysis and Terminology Analysis, this component identifies the most effective management strategy to prevent MIS from reaching the national border. Based on the identified species or pathways and the availability of resources, this component helps determine the relevant international policy instruments and management measures. If resources and management measures are available, preventive actions can begin immediately; if not, planning for resource mobilisation and development of management measures take place. This approach also considers long-term biosecurity solutions.

- **Monitoring and Evaluation**

Monitoring and Evaluation ensures the effectiveness of preventive measures identified through Pathway Analysis and Terminology Analysis. This component involves continuous assessment of international policy instruments and management strategies. Regular monitoring detects emerging risks or shifts in introduction pathways, providing early warning signs. Evaluation enables adaptive management,

refining strategies based on feedback. This stage ensures that resources, stakeholders, and measures remain active and responsive, keeping pre-border biosecurity efforts resilient.

The proposed guidance is flexible and iterative, allowing each component to be revisited as new information or resources become available. This adaptability is crucial for managing the dynamic nature of marine invasive species, enabling proactive and resource-efficient responses. When a specific species is known, Terminology Analysis guides action. If the species is unknown, Pathway Analysis helps mitigate risks from potential introduction routes.

2.4 Conclusion

Approximately 61,320,000 marine species are transferred annually around the world in ballast water in the hulls of ocean going ships alone (GEF-UNDP-IMO GloBallast Partnerships Programme 2017). The development of international policy instruments to address this issue has taken centuries (Figure 2.1), and attempting to create comprehensive, pathway-specific conventions for every possible introduction route would be neither feasible nor effective. Furthermore, predicting future invasions is particularly difficult, as many emerging species remain unidentified, making it hard to anticipate their impacts (Essl et al. 2018; Seebens et al. 2018). This uncertainty is further compounded by the lack of clear, standardised terminologies across jurisdictions (Soto et al. 2024). Hence, the urgent need for applied solutions to address the complexity of MIS introductions.

However, several existing conventions already provide a strategic foundation that can be leveraged more efficiently. Considering these challenges, a more effective approach is to categorise MIS along with their associated introduction pathways and apply the most appropriate existing instruments to each category. While a pathway-focused approach is essential for addressing high-risk pathways with significant impacts, it does not necessitate the creation of new policy instruments for every potential pathway. Instead, leveraging existing instruments in a pathway-informed manner enables more efficient implementation and enforcement.

This approach saves valuable time and resources while supporting informed decision-making at international, regional, and national levels. This study contributes to this effort by mapping categories of MIS and their introduction pathways against existing policy instruments to facilitate targeted and effective management.

Chapter 3: Adequacy of international policy instruments in safeguarding small island developing states from marine invasive species threat

3.1 Introduction

The overarching research question guiding this chapter is: ***“Are existing international policy instruments adequate in safeguarding small island developing states from marine invasive species threats?”***. In Chapter 2, I conducted a two-stage review to systematically identify and analyse 34 international policy instruments relevant to MIS management, assessing their coverage of MIS categories and introduction pathways. This involved a detailed textual analysis to review, record, and categorise the terminology used to define invasive species, the introduction pathways addressed, the type of introductions, and the nature and scope of implemented measures. All relevant data were extracted and recorded using Microsoft Excel, with categorisation summarised in Table 2.1, Chapter 2. Refer to Chapter 2 for the detailed methodology. In the present Chapter, I apply a “secondary evaluation” to leverage the findings from Chapter 2 to delve deeper into the adequacy of these 34 identified instruments in safeguarding small island developing states (SIDS) from MIS threat.

3.1.1 Small Island Developing States vulnerabilities

Small island developing states are a group of 39 United Nations (UN) Member States and 18 Associate Members of United Nations Regional Commissions, primarily located in the Caribbean, Pacific, and AIS (Atlantic, Indian Ocean and South China Sea) regions (UN-OHRLLS 2025) (Figure 3.1). They share common issues, often not faced by larger states. SIDS particularities stem from a complex interplay of inherent characteristics and vulnerabilities such as their small size, remoteness, and ecologically fragile nature, compounded by significant economic and social vulnerabilities that are exacerbated by climate change and external shocks (OECD 2018; UN-OHRLLS 2017; United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022). They were first recognised as a special case for environment and development at the 1992 UN Conference in Rio. Since 1994, SIDS have been actively fighting to address their unique and profound vulnerabilities, leading to frameworks like the Barbados Programme of Action (1994), the Mauritius Strategy (2005), and the SAMOA Pathway (2014) for the mobilisation of sustained international support for their sustainable development (UN-OHRLLS 2015). The interconnected vulnerabilities that SIDS face across environmental, economic, and social dimensions (United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022) are outlined below.



Figure 3.1 Shows the Small Island Developing States across the Caribbean, Pacific, and AIS (Atlantic, Indian Ocean and South China Sea) regions (image adapted from UN-OHRLLS (2017)).

3.1.1.1 Environmental vulnerabilities

SIDS face multiple environmental vulnerabilities making them highly susceptible to ecological and climate-related impacts. Although they contribute to under one percent of worldwide greenhouse gas emissions, SIDS are disproportionately affected by climate change. For example, rising sea levels from climate change threaten their low-lying coastal areas through inundation, erosion, and saltwater intrusion (The UN Office of the High Representative for the Least Developed Countries 2015; UNEP 2014). SIDS are also considered global biodiversity hotspots as they are home to extraordinary biological diversity, including high species endemism, but their fragile ecosystems are highly vulnerable to habitat loss, pollution, invasive species and climate-related pressures (UN-OHRLLS 2017; UNEP 2014; Zitoun et al. 2020). Challenges in waste and pollution management further exacerbate these environmental risks (Birchenough 2023; The UN Office of the High Representative for the Least Developed Countries 2015; UNEP 2014; Weeks and Adams 2018; WHO 2021; Zitoun et al. 2020).

3.1.1.2 Economic vulnerabilities

In addition to environmental vulnerabilities, a range of economic challenges also significantly hinder the sustainable development and resilience of SIDS (UNEP 2014). SIDS have narrow and undiversified economies as they rely mainly on a few industries like tourism, natural resource extraction or commodity exports (UNEP 2014). This makes them vulnerable to high risks from external economic shocks and global market fluctuations (UNEP 2014). Many SIDS also carry heavy debt and have limited budgets. Their revenues are small and unstable, while the costs of providing public services are high (OECD 2018; United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022). Natural disasters exacerbate the risk, at the cost of long-term development (OECD 2018; United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022). The introduction of marine invasive species also creates significant economic burdens for resource limited SIDS through management costs, tourism losses, and ecosystem service degradation. A well-known example of this is the introduction of the lionfish in the Caribbean SIDS that has posed significant impacts on these islands. This burden is particularly acute for SIDS because they must allocate limited resources to ongoing management while simultaneously experiencing reduced tourism revenue and ecosystem service losses. (Alemu I, Schuhmann and Agard 2019; Ali, Collins and Peachey 2013; Frazer et al. 2012; Graham, RE and Fanning 2017; Malpica-Cruz et al. 2017; Mulgrew 2020).

Accessing development finance is another challenge for them as the application processes are complicated and the eligibility criteria is mainly based on GDP. Hence, wrongly classifying SIDS as

“too wealthy” for support despite their underlying vulnerabilities (OECD 2018). Delivering aid costs nearly 4.7 times more than in other developing countries, forcing them to depend on a few donors and accept aid split into many small, short-term projects (OECD 2018; United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022). They also possess a fragile private sector that is usually small and prone to disruptions. In some cases, foreign ownership results in limited alignment with national priorities, constraining its contribution to both development and resource protection (Galaiti et al. 2023; United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022).

3.1.1.3 Social and human vulnerabilities

Health issues are also significant contributors to SIDS’ vulnerabilities with populations experiencing both diseases linked to poverty, such as child stunting and infections from unsafe water, and lifestyle-related conditions like diabetes, obesity, and heart disease, which are further aggravated by climate change (Scandurra et al. 2018; Thompson et al. 2023; UN-OHRLLS 2015). Their healthcare systems are often weak, with inadequate healthcare infrastructure and shortages of trained professionals (UNEP 2014; World Health Organization 2021). Food security is another concern, since many SIDS depend heavily on imported food and are vulnerable to trade disruptions, particularly under changing climate conditions (Scandurra et al. 2018; Thompson et al. 2023; UN-OHRLLS 2015). Human capacity is also constrained, as many skilled workers leave for better opportunities abroad, creating a “brain drain” (OECD 2018; UNEP 2014). At the same time, globalisation and modern economic systems are eroding cultural heritage and traditional knowledge that has long supported sustainable living. This valuable knowledge is not being fully used to strengthen their resilience and address their vulnerabilities (UNEP 2014; United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022; World Health Organization 2021). Together, these challenges make it difficult for SIDS to manage complex tasks like securing finance, monitoring projects, or carrying out risk reduction work (United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022).

3.1.2 *Marine invasive species intensifies the vulnerabilities of SIDS*

Introduced invasive species (both aquatic and terrestrial) represent the second leading threat to global biodiversity after habitat destruction (Altman and Whitlatch 2007). They are also recognised as one of the five direct drivers of change in nature, alongside land and sea use change, direct exploitation of organisms, climate change, and pollution (Christian 2023; IPBES 2019). The widespread negative impacts of invasive species on indigenous species, ecosystems, and human well-being are continuing

to increase globally (IPBES 2019). This threat is particularly pronounced for SIDS, where the combination of ecological fragility, limited management capacity, and the presence of unique endemic species heightens both the complexity and severity of risks associated with marine invasions (UN-OHRLLS 2017), which are further compounded by climate change (Bush 2018; GEF-UNDP-IMO GloFouling Partnerships 2018; Mauritius Attractions 2008-2021).

Small Island States are also known as Large Ocean States, as they occupy less than 1% of global land area yet are responsible for managing approximately 14% of the world's coastlines and nearly 23.2 million km² of Exclusive Economic Zones (EEZ) (around 30% of the world's oceans and seas) (World Health Organization 2021). Most of their ecosystem services (recreation, tourism, fishing, aquaculture and agriculture) are provided by natural resources and endemic species that come from these coastlines and EEZ (Roberts et al. 2002; World Health Organization 2021). These endemic species, having evolved in isolation, often lack natural defences against invaders, making them exceptionally susceptible to disruption and extinction (Sorte, Williams and Carlton 2010). According to Bellard, Cassey and Blackburn (2016), most documented extinctions in which introduced invasive species were identified as a driver have occurred among island endemic species, accounting for approximately 86% (115 out of 134 species) of such cases.

The critical dependence of SIDS on shipping, trade, and aquaculture, three major pathways for the introduction of MIS (Table 1.1) greatly amplifies the exposure of their endemic species, heightening ecological vulnerability and increasing the risk of biodiversity loss (Bush 2018; GEF-UNDP-IMO GloFouling Partnerships 2018; Mauritius Attractions 2008-2021). Similarly, their extensive ocean stewardship poses significant challenges in safeguarding and effectively managing these vast and vulnerable marine resources (OECD 2018; UN-OHRLLS 2015). In fact, even though invasive species cause large-scale degradation and species extinction on islands, it is still a serious threat that is under-acknowledged (Dulloo, Kell and Jones 2002; UNEP 2014). This represents a critical overarching challenge that significantly exacerbates the interconnected environmental, economic, and social vulnerabilities of SIDS.

Key complexities in addressing MIS include the inherent difficulty in detecting and monitoring aquatic introductions and slow, reactive international policy development, often hampered by a lack of clear, standardised terminology (Cuthbert et al. 2021; Keller. et al. 2011; Ojaveer et al. 2015; Zitoun et al. 2020). Chapter 2, addresses these complexities by identifying 20 international policy instruments directly relevant to MIS and 14 international policy instruments indirectly relevant to MIS, observing considerable overlap in their coverage of MIS categories and key pathways like *Shipping*, *Trade*, and *Aquaculture*. An innovative framework was also proposed in Chapter 2, to leverage these existing instruments more efficiently, strengthening cost-effective pre-border biosecurity rather than creating

new, costly conventions. This approach will facilitate targeted and effective management, saving time and resources.

However, limited financial and technical resources often restrict long-term monitoring efforts of SIDS (Komul Kalidin, Mattone and Sheaves 2020; OECD 2018; Robinson, S-a 2018; Uitto, Kohlitz and Todd 2017), making it crucial to prioritise surveillance based on *ecological threats of MIS (ecological threats)*, *resources available for response (resource availability)*, and *the implications of invasions for livelihood (livelihood implications)*. Without targeted and cost-effective management strategies, SIDS remain highly vulnerable to biodiversity loss, fisheries disruptions, and food security threats. To address the unique vulnerabilities and capacities challenges of SIDS, as well as regulatory gaps that hinder the effective management of MIS in SIDS, this study aims to develop a comprehensive understanding of the effectiveness of existing international policy instruments by answering the question: ***“Are existing international policy instruments adequate in safeguarding Small Island Developing States from marine invasive species threats?”***. This study maps the 34 international policy instruments identified as relevant to MIS (Chapter 2) against three critical management priorities of SIDS: *ecological threats*, *resource availability*, and *livelihood implications*, to assess whether they adequately address these management priorities.

The matrix analysis incorporates voluntary and mandatory instruments to reflect the full spectrum of international measures relevant to MIS. To complement this, participation status in mandatory instruments was also examined, as these are formally ratified, monitored, and enforceable, providing a reliable and comparable basis for assessing the extent of engagement of SIDS with binding measures that underpin the identified critical management priorities.

3.2 Methods

3.2.1 Document selection.

The 34 international policy instruments identified as relevant for addressing MIS in Chapter 2 were retained for this study to undergo a secondary evaluation. While the initial selection methodology is detailed in Chapter 2, this Chapter applies a specific matrix approach to assess these instruments against the three critical management priorities of SIDS.

3.2.2 Data extraction, charting and synthesis

Recognising the unique vulnerabilities, resource limitations, and economic dependencies of SIDS, this assessment introduces SIDS-centric evaluative criteria and a conceptual framework (Table C1). This framework was developed based on the three interconnected management priority criteria: *ecological threats considerations*, *resource availability considerations*, and *livelihood implications considerations* to assess the adequacy of international instruments in safeguarding SIDS from MIS threats. These criteria are interconnected as resource availability shapes the types of measures that can realistically be implemented, while effective protection against MIS safeguards ecosystems and the socio-economic services they provide.

By focusing on these three management priorities, the “secondary evaluation” directly addresses the unique vulnerabilities and capacities of SIDS, leading to practical and actionable insights for strengthening marine biosecurity in these critical regions. To assess the adequacy of the 34 international policy instruments in safeguarding SIDS against MIS threat, a detailed textual analysis was conducted based on specific evaluation criteria developed for each management priority criteria. All relevant data were extracted and recorded in Table C1.

3.2.2.1 Evaluation criteria for each management priority

Specific evaluation criteria were developed for each management priority to enable a systematic assessment of the 34 international policy instruments. The *Ecological threats considerations* criterion, evaluates whether the instruments addressed primary and secondary introduction pathways to prevent the introduction of MIS, included ecosystem protection measures through preventive and/or corrective approaches to prevent MIS introduction and response to incursions and included accountability mechanisms through voluntary or mandatory measures. The *Resource availability considerations* criterion evaluated the practicality of implementing the measures given the financial, technical, and human resource constraints in SIDS. The *Livelihood implications considerations* criterion focused on whether the measures help protect the ecosystem services to the community by measures that prevent or control the introduction or spread of MIS.

To operationalise these management priorities, six sub-criteria were applied in the assessment of each instrument:

1. Addressing primary and secondary introduction pathways.
2. Mitigation of MIS impacts and protection of livelihoods.
3. Inclusion of preventive and/or corrective measures.
4. Nature of measures (voluntary vs. mandatory).
5. Accountability mechanisms (monitoring, reporting, compliance). The criteria used to classify accountability are outlined in Table 3.1.
6. Feasibility with respect to SIDS resource limitations.

Table 3.1 *Criteria used to classify Accountability of International Instruments.*

High Accountability	Moderate Accountability	Low Accountability
Instrument includes legally binding measures, reporting mechanisms, inspections, and sanctions	Instrument provides recommendations or frameworks with some national-level enforcement	If instrument is voluntary, non-binding, and/or lacks enforcement mechanisms

3.2.2.2 Adequacy classification

Given that the six sub-criteria are interconnected and collectively reflect the three overarching management priorities, *overall adequacy* of instruments was determined based on performance across all sub-criteria:

- **High Adequacy** – All six sub-criteria satisfactorily addressed.
- **Moderate Adequacy** – One or two sub-criteria not fully addressed.
- **Low Adequacy** – More than two sub-criteria not addressed.

This approach ensures that ecological, socio-economic, and resource feasibility dimensions are systematically evaluated, and that gaps in any dimension are reflected in the overall adequacy classification.

3.2.2.3 SIDS participation in mandatory policy instruments as an indicator for adequacy

The criteria used to classify accountability of international instruments (Table 3.1) and the criteria used to classify adequacy were also applied to evaluate SIDS participation in mandatory international instruments. The participation of SIDS in mandatory international instruments was assessed by compiling a matrix of ratified and enforceable measures relevant to MIS. Each country's status as a party to these instruments was recorded, providing a consistent and comparable dataset. Participation was selected as an indicator because ratification represents both a formal commitment and a legal obligation that can be monitored and enforced. This focus on mandatory measures was chosen because, unlike voluntary guidelines, they are systematically recorded and consistently applied, providing a reliable basis for cross-country comparison. Voluntary guidelines, while valuable in offering recommendations, lack binding force, official records, and systematic reporting, making them unsuitable for this type of analysis. Limiting the assessment to mandatory instruments therefore ensured that findings were grounded in measures most likely to be implemented in practice and representative of SIDS' capacity to address critical management priorities.

3.3 Results and discussion

3.3.1 Adequacy of instruments in safeguarding SIDS

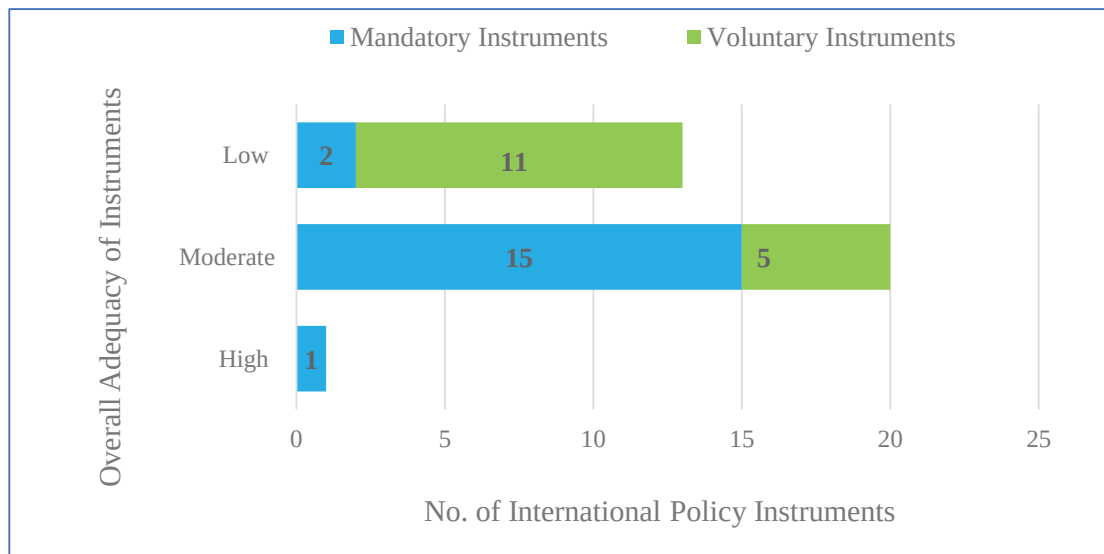


Figure 3.2 Number of international policy instruments that have an overall high, moderate or low adequacy in safeguarding small island developing states against the marine invasive species threat.

The analysis revealed that all 34 instruments address primary introduction pathways, with 17 instruments also targeting secondary introductions. All instruments include preventive measures, and 15 also incorporate corrective measures. Of these, 18 mandatory instruments mostly provide high accountability, with a few offering moderate or low accountability, whereas 16 voluntary instruments primarily provide low accountability, with a few providing moderate accountability. This indicates that the majority of international policy instruments, those addressing primary introduction pathways, providing preventive measures, and offering high to moderate accountability, meet the *Ecological threats* and *Livelihood implications considerations*. However, the *Resource availability considerations* criterion is largely unmet, as most instruments require substantial financial, technical, and human resources, posing significant implementation challenges for SIDS (Table C1).

Overall, the analysis shows that the majority of the international policy instruments provide a moderate level of adequacy in safeguarding SIDS against MIS. Out of the 34 instruments assessed, only one (Anti-Fouling Convention 2001) was found to be highly adequate, meeting all the criteria. Twenty instruments were moderately adequate not meeting one or two criteria, while 13 instruments were of low adequacy, not meeting more than two criteria (Figure 3.2 and Table C1). This distribution shows that while some instruments meet the necessary criteria for addressing the three critical management priorities of SIDS, most fall short in important respects.

When considering the nature of the instruments, the single highly adequate instrument is mandatory, whereas the 13 instruments with low adequacy are largely voluntary. This highlights the limited protection that non-binding measures provide (McNeely et al. 2001; Meliane and Hewitt 2005). Among the moderately adequate instruments, 15 are mandatory and five are voluntary (Table C1), illustrating that adequacy is not only influenced by the design of the measures but also by whether they carry enforceable commitments that can help offset the technical and financial constraints of SIDS.

Voluntary instruments are particularly problematic for SIDS, as the absence of binding obligations combined with limited resources reduces the likelihood of effective implementation. For example, in Pacific SIDS, the pooling initiatives for regional service delivery have fallen short, due to political unwillingness to cede power or allocate limited resources (Dornan and Newton Cain 2013). Voluntary regionalism often hinders effective regional action, particularly where there is no constitutional mandate for countries to pool functions (Dornan and Newton Cain 2013). This mirrors broader issues in MIS management, where binding regulations are rare, leaving critical pathways ungoverned by enforceable mechanisms (Meliane and Hewitt 2005; Stokes, O'Neill and McDonald 2004). Even comprehensive instruments like the ICES Code of Practice 2005 on the Introduction and Transfer of Marine Organisms are “only voluntary” (Meliane and Hewitt 2005).

Compliance with such voluntary measures often relies on individual state's interest and pressure from other countries which is often insufficient without a formal legal basis for enforcement to ensure

consistent action (Stokes, O'Neill and McDonald 2004). These findings point to significant gaps in the international policy framework, suggesting that existing instruments, while valuable, are not fully sufficient to safeguard SIDS against the complex risks posed by MIS.

To illustrate this critical distinction and its implications for SIDS, Table 3.2 provides a direct comparison of the Ballast Water Management Convention (2004) and the 2023 IMO Biofouling Guidelines, highlighting their fundamental differences in approach, regulation, and accountability.

Table 3.2 *A comparison of the Ballast Water Management Convention (2004) and the 2023 IMO Biofouling Guidelines, focusing on their approach, regulation, and accountability.*

Ballast Water Management Convention	IMO Biofouling Guidelines
Precautionary approach	Precautionary approach
Mandatory	Voluntary
International Ballast Water Management Certificate	No certification
Ballast Water Management Plan	Biofouling Management Plan
Ballast Water Record Book	Biofouling Record Book
Standards for maximum number of viable organisms	New standards for biofouling rating. However, cleaning with capture is not recommended for Rating 1 – microfouling, which might contain potential dangerous biological structures like pathogens.
Organisms are treated or contained in the ballast tanks until discharged.	Organisms are in direct contact with environment.
Accountability through the polluter pays principle: sanctions in case of violation	No polluter pays principle – No accountability

As demonstrated in Table 3.2, while both instruments adopt a precautionary approach, the mandatory nature of the Ballast Water Management Convention (2004) means that signatory states are legally bound to respect its preventive measures and specific rules. This includes requirements for an International Ballast Water Management Certificate, a Ballast Water Management Plan, and a Ballast Water Record Book, alongside standards for viable organisms and the crucial “*polluter pays principle*” (*Principle 16 of the Rio Declaration on Environment and Development (1992)*) for violations. These provisions create a foundational international safeguard, offering a level of protection that the voluntary

ship biofouling guidelines simply cannot match due to their lack of binding obligations, formal certification, and accountability mechanisms. The critical distinction lies in the enforceability and the direct contact of hull fouling organisms with the environment, posing a continuous and underregulated threat. Even though not all SIDS have ratified the Ballast Water Management Convention (2004) (only 20 out of 57 SIDS) (Table 4.5), its mandatory nature still provides a level of protection to SIDS that voluntary guidelines cannot.

3.3.2 Adequacy of instruments addressing key MIS introduction pathways threatening SIDS

Given their interconnected environmental, economic, and social vulnerabilities, SIDS need precautionary and cost-effective measures to identify biosecurity risks early and stop risk material from arriving at the border (Bland, Lucie M. et al. 2024; United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022). The key pathways particularly significant for introducing risk material in SIDS are *Shipping*, *Trade* and *Aquaculture* (Table 1.1) as they depend heavily on imports and exports of essential goods and the introduction of aquaculture species for food security (Bush 2018; GEF-UNDP-IMO GloFouling Partnerships 2018; Mauritius Attractions 2008-2021). Therefore, preventive measures targeting these major introduction pathways will be the most effective for SIDS, particularly due to their limited resources (OECD 2018; UNEP 2014).

Findings from Chapter 2 shows that most international policy instruments are broadly relevant to addressing all categories of marine invasive species introduced via these major key pathways (Chapter 2, Table 2.2). Trade is addressed by the highest number of instruments (14), followed by Shipping (11) and Aquaculture (8) (Chapter 2, Table 2.2). This indicate that the full range of MIS introduced through these critical pathways is being addressed at the international level.

However, the analysis of the adequacy of these instruments to meet the three critical management priorities of SIDS showed that these instruments are not fully sufficient to safeguard SIDS against the complex risks posed by MIS. The analysis of international instruments addressing *Shipping*, *Aquaculture*, and *Trade*, the critical pathways for MIS introductions also reveals significant gaps in governance for SIDS. For Shipping, only one instrument is directly relevant and mandatory, while four are directly relevant but voluntary. The remaining six instruments are indirectly relevant, indicating that most regulations do not explicitly target MIS. Trade shows a mix of two directly relevant mandatory instruments and seven directly relevant voluntary instruments, alongside five indirectly relevant mandatory instruments. Aquaculture is addressed exclusively through voluntary measures (9) (Figure 3.3), although some aquaculture risks are also indirectly covered by trade-related instruments (Table C1). Overall, these results indicate that critical pathways for MIS are often insufficiently

regulated, relying heavily on voluntary guidance or indirect coverage, which may limit effective implementation in resource-limited SIDS. Given the partial coverage of aquaculture by trade measures, the *Shipping* pathway emerges as the primary vector requiring additional directly relevant and mandatory measures (Figure 3.3) to better protect SIDS.

The next section further explores the adequacy of international instruments through participation of SIDS in mandatory instruments, reflecting the extent to which binding measures address critical management priorities and the capacity of SIDS to implement them.

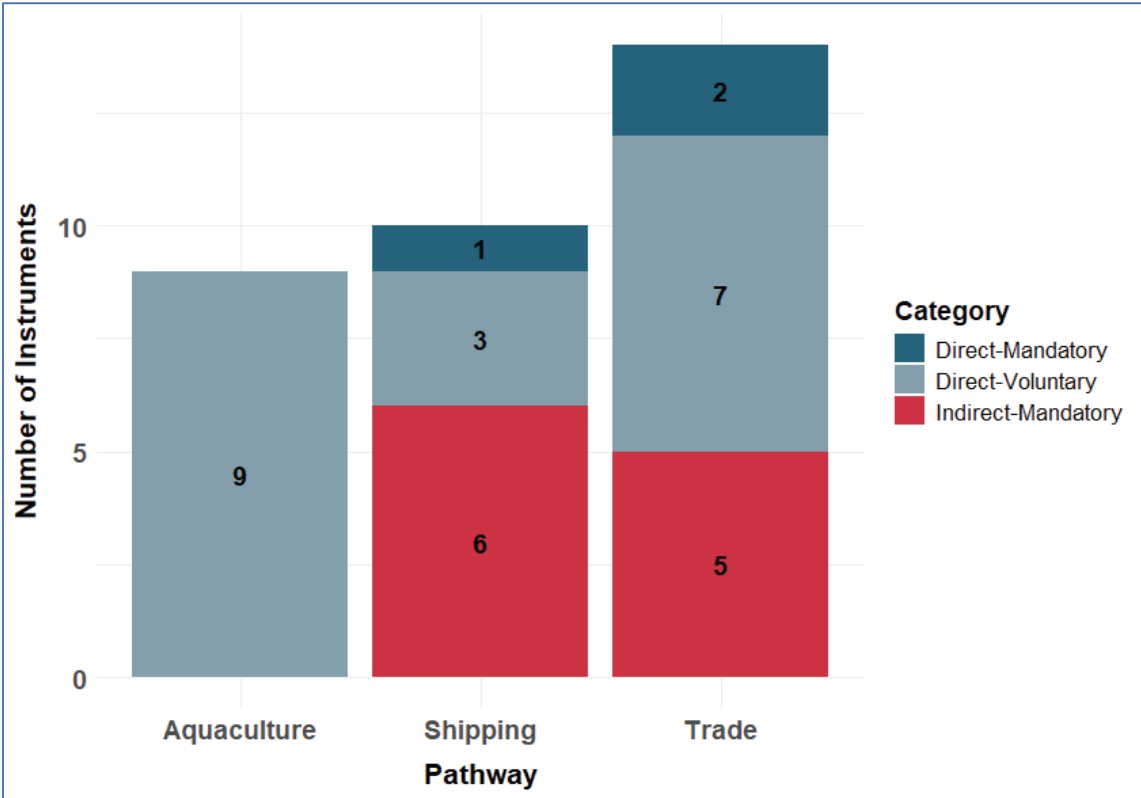


Figure 3.3 Number of international instruments addressing Shipping, Aquaculture, and Trade, critical pathways for marine invasive species introductions in Small Island Developing States, categorised by relevance to MIS and type of measure. Directly relevant instruments specifically target MIS in the pathway, while indirectly relevant instruments address the pathway without explicitly targeting marine invasive species. Mandatory and voluntary measures are distinguished to highlight gaps in governance. No instruments were found to be both indirectly relevant and voluntary for these pathways.

3.3.3 SIDS participation as an indication of instruments adequacy

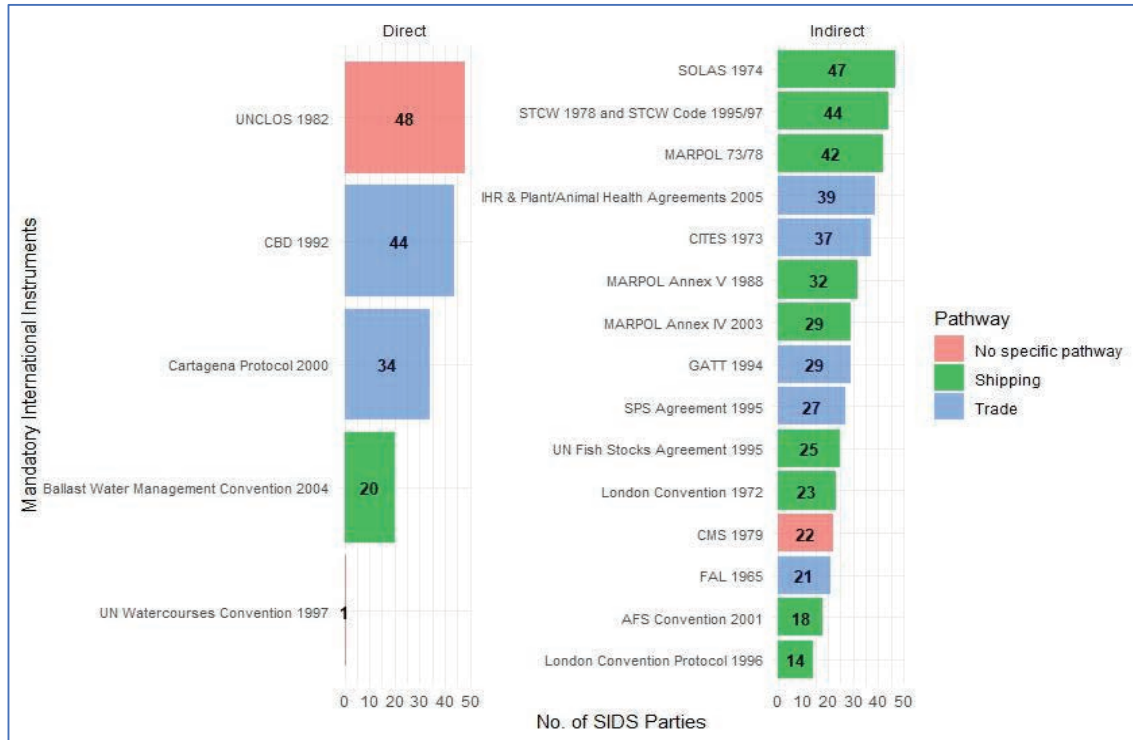


Figure 3.4 SIDS participation in mandatory international instruments, grouped by pathway and separated by relevance to MIS (Direct vs. Indirect). Bar lengths indicate the number of SIDS parties, with colours distinguishing the MIS introduction pathway.

Table 3.3 *List of the mandatory international policy instruments relevant to marine invasive species, indicating the pathways they target and their overall adequacy for Small Island Developing States.*

Guide/Convention/Protocol	Pathway	Relevance	Overall Adequacy
Convention on the Facilitation of International Maritime Traffic (FAL) as amended 1965	Trade	Indirect	Moderate
Convention on International Trade in Endangered Species (CITES) 1973	Trade	Indirect	Moderate
International Convention for Safety of Life at Sea (SOLAS) as amended including the ISM Code 1974	Shipping	Indirect	Moderate
Convention on the Conservation of Migratory Species of Wild Animals (CMS) 1979	No specific pathway	Indirect	Moderate
United Nations Convention on the Law of the Sea (UNCLOS) 1982	No specific pathway	Direct	Moderate
MARPOL 73/78, Annex IV 2003 & Annex V 1988	Shipping	Indirect	Moderate
Convention on Biological Diversity (CBD) 1992	Trade	Direct	Moderate
General Agreement on Trade and Tariffs (GATT) 1994	Trade	Indirect	Moderate
WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) 1995	Trade	Indirect	Moderate
Agreement for the Implementation of the Provisions of UNCLOS relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) 1995	Shipping	Indirect	Moderate

London Convention 1972 & London Convention Protocol 1996	Shipping	Indirect	Low
Convention on the Law of Non-navigational Uses of International Watercourses 1997	No specific pathway	Direct	Moderate
International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) and the Seafarer's Training, Certification and Watchkeeping Code (STCW Code) 1978/95/97	Shipping	Indirect	Moderate
Cartagena Protocol on Biosafety 2000	Trade	Direct	Moderate
The Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2001	No specific pathway	Indirect	Moderate
International Convention on the Control of Harmful Anti-fouling Systems on Ships (Anti-Fouling Convention) 2001	Shipping	Indirect	High
International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004	Shipping	Direct	Moderate
International Health Regulations (IHR) and plant and animal health agreements 2005	Trade	Indirect	Low

Analysis of participation of SIDS in mandatory international instruments reveals that while these measures provide an enforceable framework, their adequacy in addressing the three critical management priorities is partial. Broad, longstanding maritime and environmental instruments, such as UNCLOS 1982 (48 SIDS), SOLAS 1974 (47 SIDS), STCW 1978 & STCW Code 1995/97 (44 SIDS), CBD 1992 (44 SIDS), and MARPOL 73/78 (42 SIDS), show high participation, indicating widespread engagement with foundational instruments and a strong willingness among SIDS to adopt measures that protect their maritime environments. In contrast, instruments directly relevant to managing MIS, but requiring substantial technical, financial, or institutional resources show lower participation. For example, the Ballast Water Management Convention (2004), which addresses shipping, a key MIS pathway has only been ratified by 20 SIDS, and the Cartagena Protocol 2000 has only been ratified by 34 SIDS. This suggests that resource constraints continue to limit adoption of resource-intensive measures (Figure 3.4 and Table 3.3).

Moreover, instruments classified as indirectly relevant were not ratified with the aim of managing MIS. SIDS engaged with these instruments primarily for broader environmental or sector-specific objectives, so any contribution to limiting MIS introductions is incidental rather than deliberate. Even though existing instruments offer useful protections and can be leveraged to support MIS management, SIDS also require targeted measures that directly address the major pathways, given their limited resources and particular vulnerabilities.

While mandatory instruments contribute to some level of ecological and livelihood safeguarding, many require substantial resources and international support, and gaps remain in coverage of critical MIS pathways and direct protection of ecosystem services (Table 3.3, Table C1). The Ballast Water Management Convention (2004), which targets shipping, a major MIS introduction pathway for SIDS, illustrates this challenge. Although binding in nature, its implementation has been inconsistent due to the high technical and financial demands it places on states (Rak and Reuland 2024). This raises concerns about the practicality of relying on voluntary measures, that not only lack enforceability but also promote nonstandard approaches and fail to provide a reliable first line of defence for SIDS.

3.4 Conclusion

This chapter critically assessed the adequacy of international policy instruments in safeguarding small island developing states from marine invasive species threats, concluding that existing frameworks offer limited effectiveness. The analysis of 34 international policy instruments revealed evident disparity. For example, the single highly adequate instrument was mandatory, while 13 low-adequacy instruments were voluntary (Figure 3.1, Table C1), highlighting the limited protection non-binding measures provide. Similarly, voluntary guidelines, such as the 2023 IMO Biofouling Guidelines, create

problematic governance gaps by lacking crucial binding obligations, certification, and accountability mechanisms like the “*polluter pays principle*”, thus failing to provide a reliable first line of defence for resource-limited SIDS. This contrasts sharply with mandatory instruments like the Ballast Water Management Convention (2004), which offer a more robust, foundational international safeguard (Table 3.2).

Persistent governance gaps were identified across critical MIS introduction pathways (*Shipping, Trade, and Aquaculture*) that threatens SIDS. Notably, the *Aquaculture* pathway is addressed exclusively through voluntary measures, and critically, ship biofouling, a significant MIS introduction pathway currently lacks any binding international regulations (Figure 3.3, Table C1). Despite recent guideline updates and the IMO’s future plans for a mandatory instrument (GEF-UNDP-IMO GloFouling Partnerships 2025), its lengthy adoption process leaves a substantial interim regulatory void, underscoring the urgent need for proactive measures.

These findings are critical for SIDS given their profound environmental, economic, and social vulnerabilities (OECD 2018; UN-OHRLLS 2017; United Nations Department of Economic and Social Affairs and United Nations Office for Disaster Risk Reduction 2022). Their limited financial, technical, and human resources not only restrict their capacity to implement resource-intensive measures and engage in long-term monitoring but also significantly limit their participation in mandatory policy instruments (OECD 2018; UNEP 2014). For instance, the Ballast Water Management Convention (2004), addressing a critical *Shipping* pathway, has only been ratified by 20 SIDS, and the Cartagena Protocol (2000) by just 34 SIDS (Figure 3.4). While ratification is influenced by multiple factors, these instruments entail implementation obligations that can be technically and financially demanding. Their comparatively lower uptake among SIDS is therefore consistent with the finding that the *Resource availability criterion*, a critical management priority for SIDS, is insufficiently addressed by most international instruments (Table C1).

The urgent need for precautionary and cost-effective preventive pre-border biosecurity measures for SIDS is paramount to identify risks early and prevent harmful introductions. However, the continued reliance on voluntary approaches for major threats like ship biofouling leaves SIDS disproportionately exposed. This highlights an urgent question, **“If international mandatory instruments are lacking for such critical pathways, what are SIDS doing to protect themselves against MIS introductions via ship biofouling?”** This unresolved challenge serves as the impetus for the subsequent chapters, which examine the ship biofouling management frameworks of SIDS and Australia. The aim is to use evidence from national measures and stakeholder perceptions to identify the specific needs and challenges of SIDS in managing ship biofouling (Chapter 4), and to assess the feasibility of adapting elements of Australia’s biofouling management approach for SIDS (Chapter 5).

Chapter 4: Small island developing states' preparedness for managing marine invasive species introduction via ship biofouling

4.1 Introduction

The transboundary nature of marine invasive species (MIS) necessitates comprehensive strategies that address all MIS categories and critical introduction pathways. However, as outlined in previous chapters, the critical pathway of ship biofouling remains insufficiently regulated at the international level, with no legally binding measures in place to provide a first line of defence for safeguarding global biodiversity against MIS. As a result, small island developing states (SIDS), which are already highly reliant on maritime activities (Bush 2018; GEF-UNDP-IMO GloFouling Partnerships 2018), must prioritise strengthening national preparedness to manage ship biofouling risks. This chapter examines the implications of a voluntary international regulatory system for SIDS by evaluating their capacity and capability to address this ongoing biosecurity challenge.

4.1.1 Implications of a voluntary instrument system for addressing ship biofouling

Biofouling organisms attached to ship hulls and fittings are now widely recognised as a more significant pathway for the introduction and dispersal of MIS across biogeographical barriers worldwide than ballast water, reflecting their much longer history as an introduction vector (Bailey et al. 2020; GEF-UNDP-IMO GloFouling Partnerships 2018, 2019d; International Maritime Organization 2025a; Lieurance et al. 2023; Molnar et al. 2008; Muscetta, Shine and Ziller 2011). Despite its global significance, biofouling remains underregulated at both the national and international levels because no binding international convention currently addresses this issue. (GEF-UNDP-IMO GloFouling Partnerships Project and GIA for Marine Biosafety 2022). Existing measures are largely voluntary, guided by the International Maritime Organization's (IMO) Biofouling Guidelines, which provide a non-mandatory framework for managing biofouling to minimise the transfer of MIS (International Maritime Organization 2025b).

The global status of biofouling management, as reported in *Compilation and Comparative Analysis of Existing and Emerging Regulations, Standards, and Practices Related to Ships' Biofouling Management*, indicates that very few countries have established biofouling policies (represented by the orange marks on the map in Figure 4.1) and a limited number of countries plan to develop such policies (yellow marks). It also shows that 12 countries have participated in the GEF-UNDP-IMO GloFouling Partnerships Project (grey marks). This IMO initiative, implemented from December 2018 until May 2025 in collaboration with the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP), was designed to build capacity in developing countries to apply the IMO

Biofouling Guidelines and other relevant guidance, while helping to reduce the international spread of MIS through biofouling (GEF-UNDP-IMO GloFouling Partnerships 2018; GEF-UNDP-IMO GloFouling Partnerships Project and GIA for Marine Biosafety 2022; International Maritime Organization 2025b).

However, although some countries have implemented national biofouling management requirements, the adoption of proactive biofouling management practices, including the development and implementation of Ship Biofouling Management Plans by ships, remains limited, largely due to the non-mandatory nature of the IMO Biofouling Guidelines (International Maritime Organization 2020). The absence of universally accepted international standards to regulate the environmental risks associated with in-water cleaning (IWC) and to test and approve IWC systems has resulted in notable variations in practices across ports and countries (GEF-UNDP-IMO GloFouling Partnerships Project and GIA for Marine Biosafety 2022). This lack of standardisation, combined with uncertainty over the responsible regulatory authority, has resulted in inconsistencies, confusion, operational delays, and potential environmental impacts (GEF-UNDP-IMO GloFouling Partnerships Project and GIA for Marine Biosafety 2022).

To address these barriers and challenges, in April 2025, the IMO announced that it had begun developing a mandatory instrument on ships' biofouling management (GEF-UNDP-IMO GloFouling Partnerships 2025). Nevertheless, the regulatory gap will persist until the implementation of binding measures, providing enough time for MIS to cause substantial environmental and economic damages. This highlights the need for proactive, pre-border measures to address biofouling and associated risks without delay.

4.1.2 Vulnerability and preparedness of SIDS to marine invasive species threat

The fundamental structural, geographic, economic, and institutional vulnerabilities of SIDS have remained largely unchanged, continuing to be exacerbated by external global threats (Agard, St. Louis and Boodram 2023; United Nations 2024). The geographical isolation of SIDS has left their indigenous species poorly equipped to cope with aggressive invasive species (Chase et al. 2011; Ministry of Lands 2013; Moultrie 2013) and the archipelagic nature of certain SIDS has increased their vulnerability to MIS introductions through multiple ports of entry (Moultrie 2013). Their fragile ecosystems are already vulnerable to external shocks such as tropical cyclones and the introduction of MIS will further weaken these ecosystems, which serve as natural defences (Agard, St. Louis and Boodram 2023; Bahamas Environment 1999; Government of Antigua and Barbuda. Department of Environment 2023b). SIDS complex economic dependencies and lack of financial space further heighten their susceptibility to external shocks and limit their response capacity (Department of Sustainable Development 2018; John and Radford 2016; United Nations 2024).

These vulnerabilities are further intensified by SIDS' reliance on shipping, trade, and aquaculture, which serve as primary pathways for MIS, and are compounded by a complex array of threats, including climate change, pollution, and the rapid growth of global trade (Bush 2018; GEF-UNDP-IMO GloFouling Partnerships 2018; Mauritius Attractions 2008-2021; Secretariat of the Pacific Regional Environment Programme (SPREP) 2023). Among these threats, MIS transported via ship biofouling represent a particularly significant risk for SIDS, which are located in regions of heavy maritime traffic (Figure 4.2). This threat endangers the unique, often endemic species and drives biodiversity declines of these geographically isolated islands (Abdulla et al. 2007; Chase et al. 2011; Moultrie 2013).

The capacity to implement effective solutions, particularly for cross-cutting issues like MIS, is hampered by long-standing institutional deficits. For example, in most SIDS, responsibility for MIS management is fragmented across multiple ministries which leads to confusion, duplication, and difficulty enforcing policies (Bahamas Environment 1999; Chase et al. 2011; Government of Antigua and Barbuda. Department of Environment 2023a; Mahot 2014; Reaser 2013; Vaas et al. 2017). Existing legislation is poorly enforced in SIDS due to lack of knowledge on invasive species issues, lack of clarity around responsibilities, policies and laws, scarce financial resources, and insufficient human capacity (Chase et al. 2011; Division of Environment and Conservation 2019; Faahi Gahua Takatakaimotu 2024; Kairo et al. 2003; Mahot 2014). The lack of a mandatory international convention specifically targeting ship biofouling leaves SIDS highly exposed, forcing reliance on fragmented and under-resourced national policies, resulting in severe inconsistencies in implementation and enforcement across the region and globally (GEF-UNDP-IMO GloFouling Partnerships Project and GIA for Marine Biosafety 2022; Kairo et al. 2003; Reaser 2013).

This global lack of biofouling management measures and existing regulatory gaps create a significant void, particularly impacting SIDS and increasing their vulnerability to the introduction of MIS via ship biofouling. Given the limited resources available to SIDS, it is crucial to implement more targeted, mandatory, and directly relevant measures to effectively mitigate hull fouling risks. In the absence of binding international measures, this can only be achieved if SIDS are prepared to protect their ecosystem services against MIS introductions via ship biofouling at the national level (Government of Antigua and Barbuda. Department of Environment 2023b; UICN Comité français 2019).

To manage ship biofouling effectively, SIDS need a resilient biosecurity system encompassing five key dimensions: awareness, preparedness, resourcing, responsiveness, and adaptability (Schneider, Karen et al. 2020). This involves understanding the threats posed by ship biofouling, identifying, assessing, and prioritising risks, and having appropriate management strategies and tools in place (Arndt, E et al. 2021; Hayes, Inglis and Barry 2019; Schneider, Karen et al. 2020). Additionally, SIDS require sufficient capacity and capability to respond to incursions and recover effectively (Anand 2018). Understanding how well SIDS meet these dimensions of preparedness is therefore critical for guiding policy and intervention efforts.

Building on this, the study evaluates the preparedness of SIDS to manage MIS introduction via ship biofouling by documenting their awareness of the issue, existing biofouling management measures, as well as the challenges and needs faced in implementing these measures. By synthesising evidence from national measures and stakeholder perceptions, this study provides the foundational data needed to develop cost-effective, targeted strategies to close regulatory gaps and strengthen marine biosecurity in SIDS.

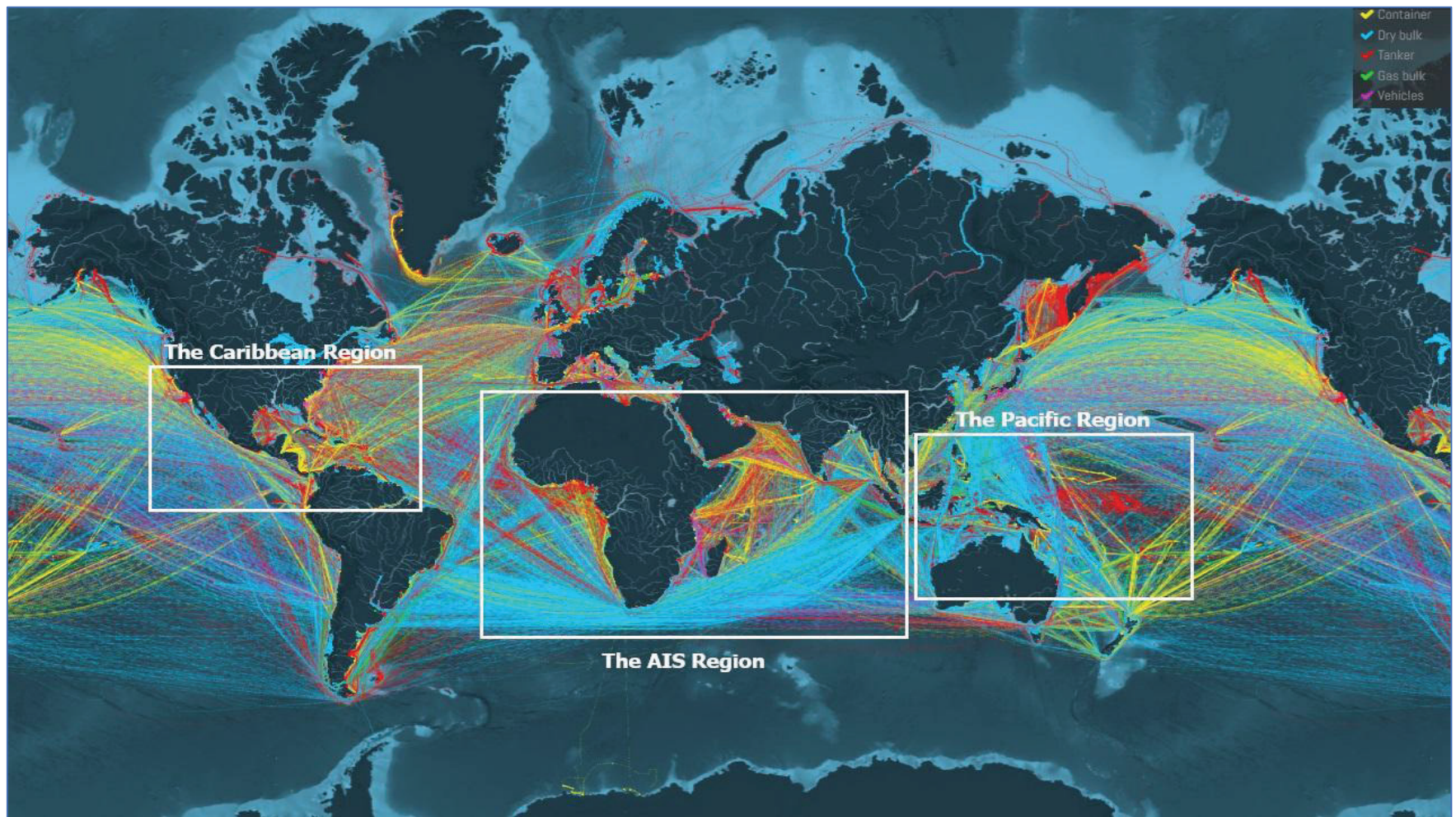


Figure 4.2 Worldwide Marine Traffic Density Map, showing that SIDS are located in busy maritime traffic regions (adapted from Shipmap.org 2025). The white boxes highlight the three geographical regions where SIDS are located, and the pathway colours represent different types of vessels.

4.2 Methods

To assess the preparedness of small island developing states in managing the introduction of marine invasive species via ship biofouling, national laws and regulations, along with national and regional policies, reports, guidelines, and conference or workshop proceedings, were reviewed for their relevance to biofouling management and invasive species control. As the analysis focuses on identifying the types of preparedness measures, needs, and challenges across countries and regions, variation in the number of documents per country does not compromise the validity of the thematic assessment.

A sequential mixed-methods design was adopted to enhance the depth and breadth of data collection across SIDS. Survey requests were initially sent to all 57 SIDS, yielding 8 responses (14.0%). To increase participation, interview requests were subsequently sent to the 49 non-responding countries, resulting in an additional 6 responses (12.2%). Due to the overall low response rate, document analysis was also conducted. This triangulated approach combined survey, interview, and documentary data to mitigate the limitations of low participation and to provide a more comprehensive understanding of the legal, institutional, and operational dimensions of preparedness among SIDS in addressing MIS introduced through ship biofouling.

The following research questions were used to investigate the preparedness of SIDS in addressing the introduction of marine invasive species via ship biofouling:

1. Are SIDS aware that ship biofouling serves as a vector for introducing marine invasive species and poses a threat to their marine ecosystems?
2. Do SIDS have management measures in place to address this threat?
3. What is the invasive species management focus of SIDS?
4. What challenges and barriers are SIDS facing in managing the introduction of marine invasive species via ship biofouling?
5. What do SIDS need to effectively manage the introduction of marine invasive species via ship biofouling?

Questions 4 and 5 serve distinct but complementary purposes. Question 4 is diagnostic, focusing on identifying the existing challenges and barriers that SIDS face in managing MIS introduction via ship biofouling. In contrast, Question 5 is forward-looking and seeks to identify the specific needs and requirements necessary for effective management. This distinction is important because the needs of SIDS are not always a direct inverse of the challenges identified. Variations in national capacity, governance structures, and priorities mean that similar challenges may result in different needs across different states (Morita, Okitasari and Masuda 2020; Stoker 2019). Additionally, limitations in awareness or technical knowledge may prevent some SIDS from fully recognising or articulating their needs. By including both questions, this research aims at capturing not only the constraints currently experienced but also the capacity gaps and support required moving forward, enabling a more comprehensive and nuanced assessment of preparedness.

Main Themes for each research questions are:

- **Awareness Level (being aware)** - Examine whether SIDS are aware that ship biofouling presents a pathway for introducing marine invasive species and understand the potential threat it poses to their marine ecosystems. Awareness levels were categorised as good, low, mixed or absent.
- **Management status (being prepared)** - Examine if SIDS have adequate mechanisms, plans, tools, agreements etc. in place (Prepare) to manage biofouling and prevent the introduction of invasive species via ship biofouling. This was completed by examining the policies, regulations, protocols, and practical actions currently implemented by SIDS.
- **Management focus (being adaptive)** - Evaluates the extent to which invasive species management efforts focus on marine or terrestrial invasives and whether they target specific species or systems-based biosecurity approach, reflecting the “Adaptive” characteristic of an effective system. The species-specific approach is reactive and narrow as it focuses on identified and listed high risk invasive species or diseases and is often initiated as a response to incursions. It has a limited adaptive capacity as it does not cater for unknowns and unlisted organisms remain unregulated (Brasier 2008; Hayes, Inglis and Barry 2019; Waage and Mumford 2008). A system-based approach focuses on managing the vectors (e.g., shipping, ballast water, biofouling) and the administrative continuum (pre-border to post-border) rather than just the species themselves. This approach is more adaptive because it uses feedback loops to monitor and adjust management measures (Bland, Lucie M. et al. 2024; Edith et al. 2024; Hayes, Inglis and Barry 2019).

- **Challenges and barriers (being resourced, responsive & adaptive)** - Assesses the capacity and capability of SIDS for managing ship biofouling, encompassing the institutional, technical, financial, and contextual challenges that constrain their ability to effectively address marine invasive species introduced through ship biofouling.
- **Needs (being resourced, responsive & adaptive)** - Examine the capacity and capability of SIDS for managing ship biofouling by identifying their expressed requirements for strengthening biofouling management, such as capacity building, funding, technical assistance, regional cooperation, policy development, and infrastructure.

These main themes were selected to assess key dimensions of biosecurity robustness and resilience, aligning with the five characteristics of an effective system (Schneider, Karen et al. 2020): being *aware*, *prepared*, *resourced*, *responsive*, and *adaptive*. For further detail on these characteristics and their contribution to system resilience, refer to Box 12 of Schneider, Karen et al. (2020), also presented in Appendix D (Figure D1) for reference. By examining *awareness level*, *management status*, *management focus*, *challenges and barriers*, and *needs*, this study provides a comprehensive evaluation of SIDS' capacity and capability to manage MIS introduced via ship biofouling.

4.2.1 Data collection and analysis

4.2.1.1 Surveys and interviews

Surveys and interviews were conducted under the approval from the JCU Human Research Ethics Committee (H8780).

4.2.1.2 Participant details

Participants were selected from individuals working at the national level in environmental management roles across the 57 small island developing states. Participants were eligible if they were major decision-makers or stakeholders with direct knowledge or responsibility for managing the introduction of MIS via ship biofouling. These included officials from national shipping administrations (e.g., Mauritius' Shipping Division of the Ministry of Agro-Industry, Food Security, Blue Economy and Fisheries) and environmental management departments (e.g., Antigua & Barbuda's Department of Environment, Ministry of Health, Wellness and the Environment).

4.2.1.3 Sampling strategy

A convenience sampling strategy was employed and eligible participants were identified through a literature review and publicly available information on government websites. Survey invitations were initially sent to all 57 SIDS and only eight countries responded to the survey (14.0%). To improve participation, interview requests were subsequently sent to the 49 non-responding countries, resulting in an additional six responses (12.2%). In some cases, more than one participant per country was recruited if multiple departments were responsible for biofouling management. Documents were translated into participants' preferred language (English, French, Spanish, Arabic, Dutch, or Portuguese), and non-English responses were back translated to ensure consistency and accuracy.

4.2.1.4 Survey administration

Surveys were conducted using Qualtrics, with the 'Prevent multiple submissions' option enabled to flag any duplicate responses. In cases where discrepancies between submissions were identified, participants were contacted via email to provide clarification.

4.2.1.5 Interview content and strategy

Interviews were semi-structured and guided by four core research questions investigating awareness of the issue, existing management measures, challenges and barriers, and needs related to ship biofouling management. Interview questions were developed based on a preliminary literature review. Participants received the interview guide in advance to allow preparation and internal coordination, given the fragmented nature of data across departments. Interviews were conducted one-on-one at JCU by teleconference, or phone, depending on participant availability. Each interview was planned to last no more than one hour. Where scheduling was a challenge, participants were given the option to respond to the interview questions via email. Consent was obtained from each participant both in writing, via an informed consent form, and verbally recorded before proceeding with the Zoom interview. The interview questions were provided in advance to allow participants adequate time for preparation.

4.2.1.6 Documentary analysis

To supplement the primary data collection, a documentary analysis was conducted predominantly on grey literature of national and regional policies, regulations, and legislation relevant to biofouling management in SIDS. Documents were identified through systematic searches using the Google.au

search engine and by reviewing the official websites of government institutions and regulatory agencies in each SIDS. All retrieved documents were initially screened for relevance, with attention to those addressing maritime, environmental, biosecurity issues, or marine invasive species. A total of 739 documents was screened, of which 87 were deemed relevant to biofouling management and retained for further analysis (Table 1D). The retained documents were then imported into NVivo 14, where themes were inductively and deductively coded to identify patterns, awareness, needs, challenges and barriers, policy gaps, and biofouling management approaches.

Table 4.1 presents the main themes and sub-themes specifically for challenges and barriers identified in the analysis and Table 4.2 presents the main themes and sub-themes specifically for needs identified in the analysis.

Table 4.1 *Main and sub-themes for challenges and barriers identified and coded in NVivo 14*

CHALLENGES AND BARRIERS	
<i>Main theme</i>	<i>Sub-themes</i>
Climate Change	Management challenges due to climate change
Data Scarcity	No data, Limited data, No robust biodiversity baseline information, Data not available or shared with other institutions, Limited risk assessment
Lack of Equipment and Technology	Lack of equipment, Lack of technology and software,
Lack of Financial Resources	Anti-fouling paint expensive, Lack of Funding, No quantification of resources allocated,
Lack of Knowledge and Expertise	Lack of Knowledge, Lack of Expertise, Low awareness of hull fouling as a vector and threat, Terminology used not understood by layman
Lack of Legislative and Institutional Frameworks	No Formal legislation, Legislative and Bureaucratic delays, Insufficient integration of environmental-economic linkages in national policy frameworks
Limited Workforce	Manpower, Human Resources
Multisectoral	Involves different stakeholders with different mandates
Lack of Political Commitment and Enforcement	Low Political Priority, Limited or no implementation of action, Weak Control or Enforcement Mechanisms
Damage not visible straight away	The ecological and economic damage caused by marine invasive species can take weeks, months, or even years to become apparent, making early detection and prevention especially challenging.

Focus on Terrestrial Invasives	Management measures are more focused on terrestrial invasive species
Jurisdictional Dependency	Overseas territories must depend on the legal authority the sovereign state
No Standardised Mandatory Measures	No consistent, uniform rules applied everywhere
Unmanaged points of entry	Ports or coastal access areas that lack official monitoring, security, or administrative control, allowing entry without systematic checks
Language Barrier	Difficulty in communicating with local communities, stakeholders, or authorities in the region where the ship is arriving, due to differences in language between those regional actors and the ship crew, inspectors, or external agencies

Table 4.2 *Main and sub-themes for needs identified and coded in NVivo 14.*

NEEDS	
<i>Main theme</i>	<i>Sub-themes</i>
Global effort	Global collaboration, Regional collaboration, Manage global introduction pathways, Preventive measures addressing the source, Standardised international mandatory measures/regulations
Data collection	Baseline data and data on marine invasive species, Data on impacts, study/research/risk assessments
Technical Infrastructure (tools, platforms, and supporting systems)	Equipment, Technology, Mechanism/System for the transfer of information, Laboratories,
Financial Support	Financial resources, Global fund, Funding, Fundraising Strategies
Technical Capacity	Training, Technical assistance, Public Awareness & Citizen Science, Risk assessments and Knowledge & Awareness of the issue, Expertise, Availability of information, Integrate marine invasive species in school curriculum, Taxonomic skills
Regulatory and Legislative Framework	Legislation, Technical guidance to develop regulations, Economic policies and tools, committed financial support,
Human Resources	Manpower, trained personnel
Lead Agency and Stakeholder Coordination	Lead Agency, Stakeholder engagement, Citizen scientist
Political Commitment and Enforcement	Political Will, Implementation action, National Strategy, Economic policies like User pays and fines, committed financial support,

4.2.1.7 Data analysis

Interview and survey responses were analysed using NVivo 14, following both inductive and deductive coding techniques. Responses were coded based on the five main thematic categories: awareness level, management status, challenges and barriers, needs, and management focus (deductive). To reduce individual-level bias during data extraction and synthesis, the process and findings were peer reviewed by my advisory panel and internal colleagues, whose input helped validate the categorisation and ensure consistency and rigour in the interpretation of the data. Themes were analysed to identify regional patterns and cross-cutting issues (inductive).

Descriptive analyses and Fisher's Exact Tests with a simulated p-value (100,000 replicates) were used to examine differences in categorical variables, including awareness levels, ship biofouling management status, invasive species management focus, and reported challenges and needs, to evaluate the preparedness of SIDS across the three geographic regions: Pacific, Caribbean, and AIS (Atlantic, Indian Ocean, and South China Sea). A Chi-square test was initially considered, as it is the standard method for testing associations between categorical variables; however, Fisher's Exact Test was employed because some expected cell counts were below five, making the Chi-square test unsuitable. For analyses conducted within individual regions, neither the Chi-square test nor Fisher's Exact Test was statistically feasible due to extremely low expected cell counts, which generated warnings about unreliable Chi-square estimates. Consequently, formal inferential statistical testing could not be performed for within-region comparisons. Instead, raw frequency counts are presented to visually illustrate the distribution of awareness levels, ship biofouling management status, invasive species management focus, and reported challenges and needs.

The current management status of ship biofouling in SIDS was assessed using the following categories:

- **Directly Managed:** Countries that have some ship biofouling management measures in place. Based on identification of specific national policies, programs, or frameworks for ship biofouling.
- **Indirectly Managed:** Countries that do not have specific management measures, but have Marine Notices or Regulations related to AFS (Anti-Fouling Systems), which may cover ship biofouling indirectly.
- **Not Managed:** Countries where no measures, no future plans, or only future plans were identified, indicating no implementation to date.

- **Unclear:** Countries where survey respondents indicated “Don't know”, meaning that data was collected, but knowledge about ship biofouling management is uncertain or not available to those surveyed.

4.2.2 *Data scope and limitations*

Due to limited participation from certain countries and the scarce availability of relevant documents, it is possible that additional needs or challenges were not captured in some cases. Therefore, the absence of data for a specific issue or country should not be interpreted as the absence of that issue, but rather as a reflection of data access and participation limitations. No data were obtained through surveys, interviews, or documents for seven of the 57 SIDS, with these countries then excluded from the analysis. Statistical analyses were performed using R version 4.3.1 (R Core Team, 2023). Non-parametric tests were used to examine whether *awareness level*, *management status*, *management focus*, *challenges and barriers*, and *needs* differed across regions. Fisher's Exact Test was used in place of Chi-squared tests due to small sample sizes and low expected cell counts, which limit the reliability of Chi-squared assumptions.

4.3 Results

The findings of this study reflect observed patterns in the available data rather than comprehensive reporting by all 57 SIDS. No information was available or found across any of the methods used for seven countries, Guam, Guinea Bissau, Haiti, Northern Mariana Islands, Puerto Rico, São Tomé & Príncipe, and U.S Virgin Islands. Consequently, the analysis presented in this study is based on the available data from the remaining 50 SIDS.

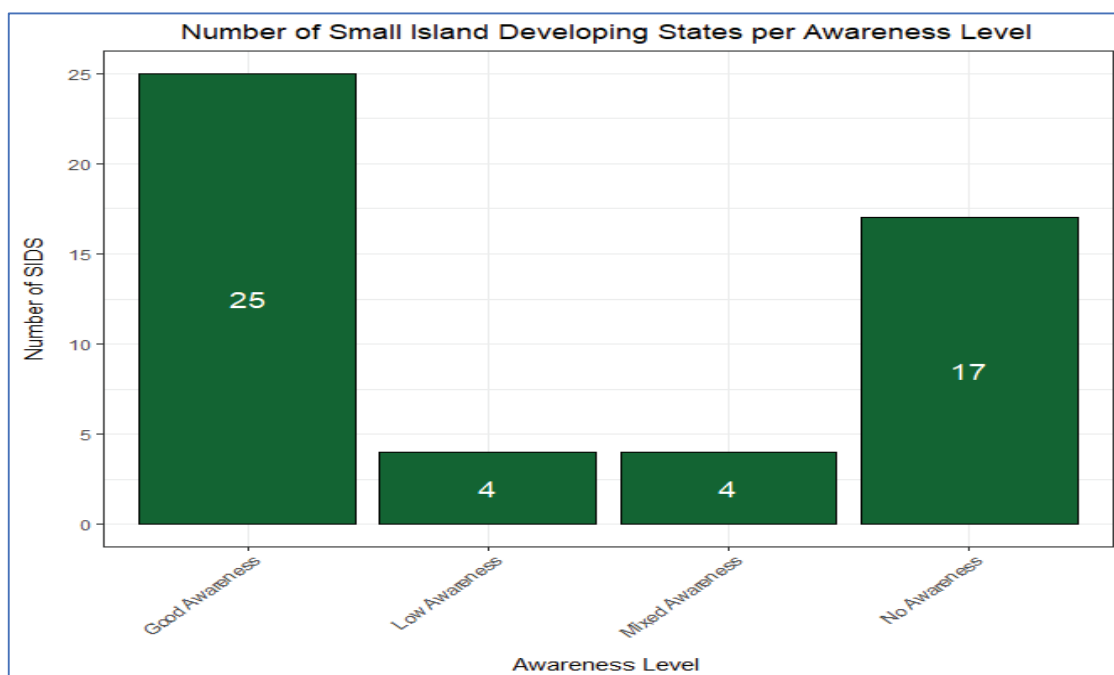


Figure 4.3 Awareness levels of Small Island Developing States regarding ship biofouling as a vector and threat.

4.3.1 Awareness of ship biofouling as a vector and threat

Awareness of ship biofouling as a vector and threat among small island developing states was assessed based on evidence recorded from surveys, interviews, and document analysis. Across these sources, 25 SIDS were recorded as demonstrating good awareness, 17 having no awareness, and a small number as indicating low (4) or mixed (4) levels of awareness (Figure 4.3). This shows that only 50% of SIDS had a good awareness of ship biofouling as a MIS introduction pathway and threat.

4.3.1.1 Awareness level across regions

Fisher's Exact Test indicated no statistically significant difference in awareness levels across regions ($p = 0.199$, two-sided), suggesting that awareness was similar among the three geographic regions.

4.3.1.2 Awareness level distribution for each region

Due to the small sample sizes available for within-region comparisons (e.g., AIS $n = 6$), Figure 4.4 presents raw frequency counts to descriptively illustrate the distribution of awareness levels. The analysis showed that within the AIS region ($n = 6$), 83% of SIDS demonstrated good awareness of ship

biofouling as a vector and threat, while 16% had no awareness, indicating generally high awareness in this region. In the Pacific region (n = 17), 64% of SIDS demonstrated good awareness and 17% had no awareness, suggesting that most countries were aware of ship biofouling risks, although a notable minority lacked awareness. In contrast, the Caribbean region (n = 27), showed greater variation in awareness levels, with 33% of SIDS demonstrating good awareness and 48% having no awareness.



Figure 4.4 Number of Small Island Developing States in each region classified by awareness levels of ship biofouling as a vector and threat. AIS represents the Atlantic, Indian Ocean and South China Sea Region.

4.3.2 Ship biofouling management status in Small Island Developing States

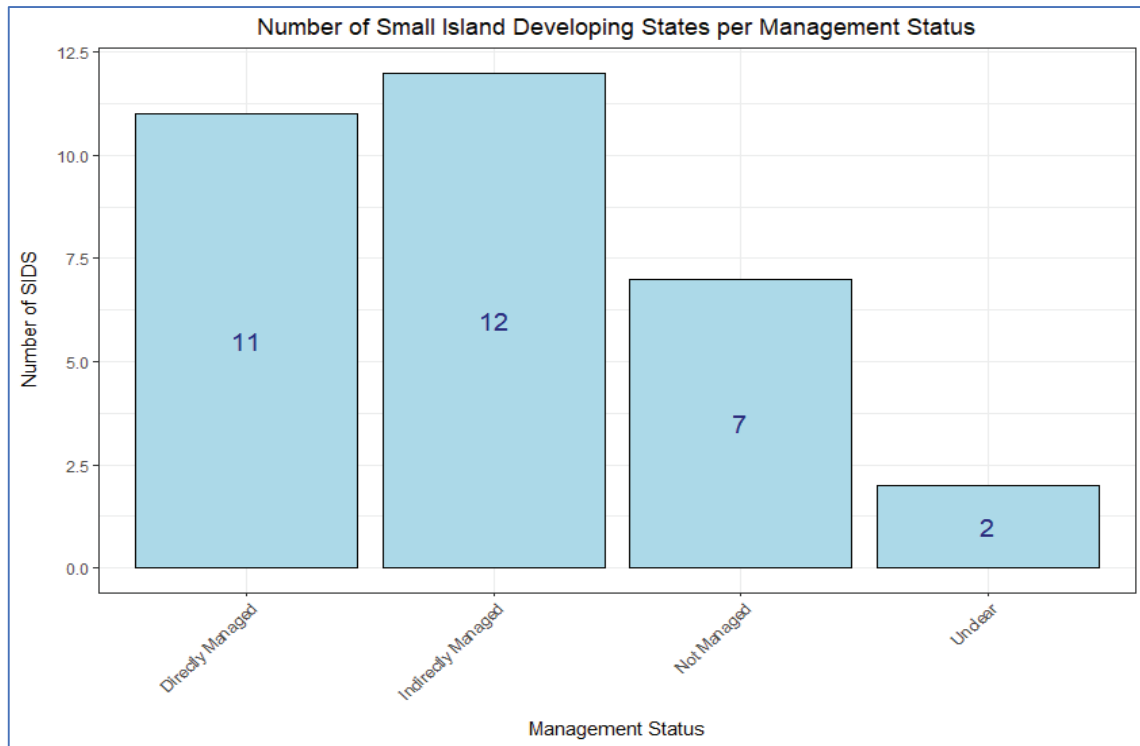


Figure 4.5 Distribution of Small Island Developing States according to management status. Data on management status were available for 32 SIDS, while 18 SIDS had no available data.

Data on ship biofouling management status were available for only 32 SIDS, while 18 SIDS had no available data. Eleven of the 32 SIDS were categorised as Directly Managed, having some national policies, programs, or frameworks in place for ship biofouling management. Twelve SIDS were classified as Indirectly Managed, with Marine Notices or regulations related to Anti-Fouling Systems (AFS) that may cover ship biofouling indirectly. Seven SIDS were Not Managed, with either no evidence of measures or only plans for future implementation. Two SIDS were classified as Unclear, where survey respondents indicated “Don’t know,” suggesting uncertainty or lack of available knowledge regarding ship biofouling management (Figure 4.5).

4.3.2.1 Ship biofouling management status across region

Fisher’s Exact Test indicated no statistically significant difference in current ship biofouling management status across regions ($p = 0.699$, two-sided), suggesting that ship biofouling management status was similar among the three geographic regions.

4.3.2.2 Ship biofouling management status distribution for each region

Due to the small sample sizes available for within-region comparisons (e.g., AIS $n = 4$), Figure 4.6 presents raw frequency counts to descriptively illustrate the distribution of management status. The analysis showed that within regions, the distribution of management status varied. In the AIS region ($n = 4$), 50% of SIDS were Directly Managed, while 25% were Indirectly Managed and 25% were Unclear, showing that half of the countries had some level of management measures in place, while the remainder had either indirect or uncertain management. In the Caribbean ($n = 15$), the distribution was more varied: 40% were Indirectly Managed, 33% Directly Managed, 20% Not Managed, and 7% Unclear, indicating that most countries had at least some indirect management measures, with a smaller proportion having some level of management measures or no management measures. In the Pacific ($n = 13$), 38% were Indirectly Managed, 31% Directly Managed, and 31% Not Managed, suggesting a roughly even spread between countries with indirect measures, direct measures, and no managed

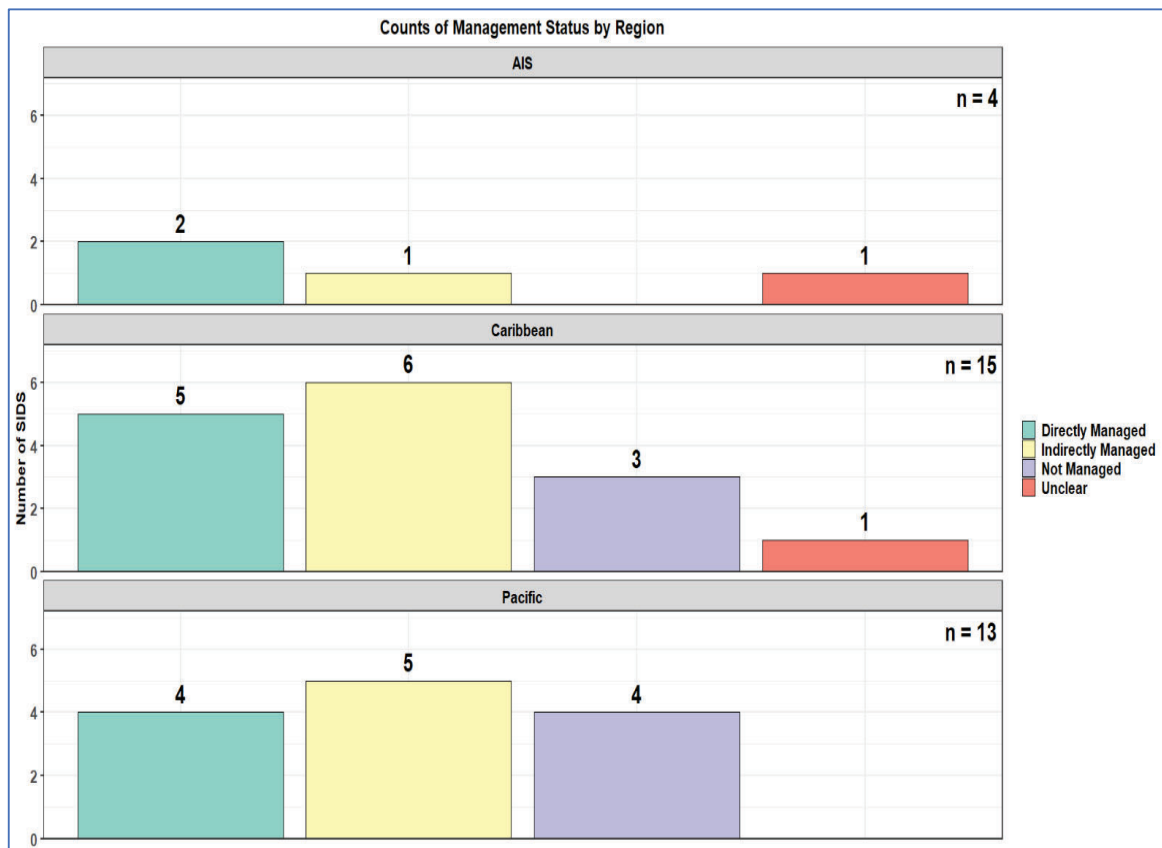


Figure 4.6 Number of Small Island Developing States in each region classified by current ship biofouling management status. AIS represents the Atlantic, Indian Ocean and South China Sea Region.

4.3.3 Invasive species management focus

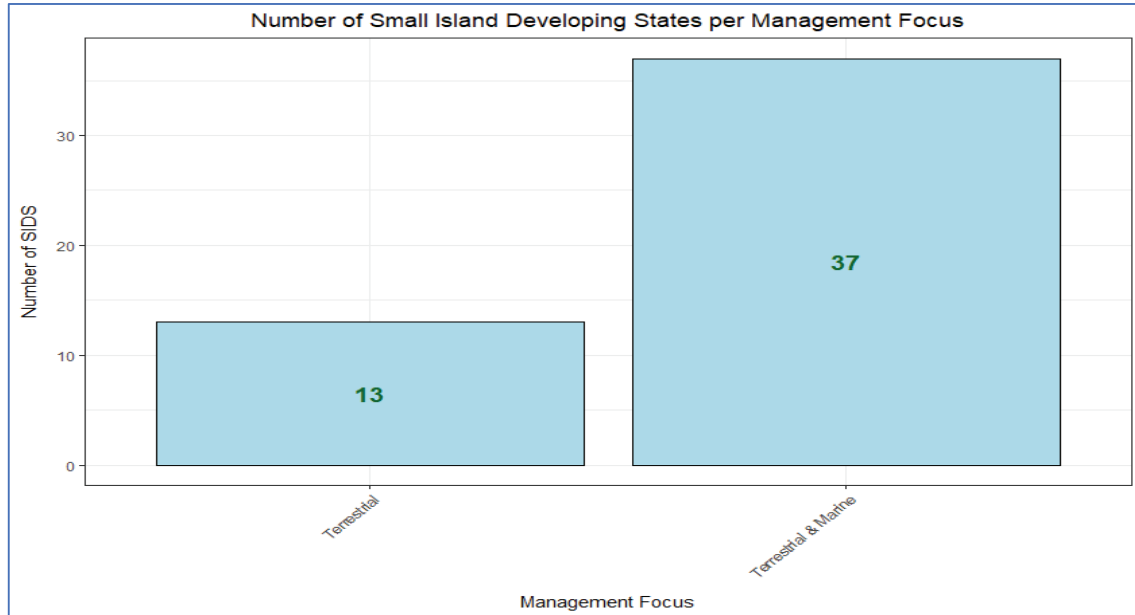


Figure 4.7 Number of Small Island Developing States classified by their management focus for invasive species.

Among the 50 SIDS reviewed, all demonstrated a focus on terrestrial invasive species management. Thirteen focused solely on terrestrial invasives, while 37 incorporated both terrestrial and marine management efforts (Figure 4.7). The marine management focus across SIDS was generally limited to a few specific marine invasive species, such as the lionfish (*Pterois volitans*), *Halophila* seagrasses (*Halophila spp.*), sun corals (*Tubastraea spp.*), and the Asian green mussel (*Perna viridis*). Only a small number of SIDS, including Mauritius, Seychelles, Singapore, Fiji, and the Cook Islands, were addressing broader marine pathways such as ballast water and biofouling, or implemented general aquatic invasive species management measures (Table 4.3). This pattern suggests that while many SIDS recognise MIS as a concern, their management approaches remain species-specific rather than pathway- or system-based.

Further evidence of the limited attention to marine invasives is reflected in the ratification status of the Ballast Water Management (BWM) Convention (2004). Only 20 out of 57 SIDS (35%) have ratified the BWM Convention (Table 4.4), highlighting the relatively limited adoption of international frameworks targeting key marine invasion pathways.

Table 4.3 *Invasive Species Management Focus in Small Island Developing States.*

Invasive Species Management Focus	Region	Terrestrial Focus	Marine Focus
Cabo Verde	AIS	Yes	-
Comoros	AIS	Yes	-
Maldives	AIS	Yes	<i>Caulerpa racemosa</i> Algae
Mauritius	AIS	Yes	Ballast & Biofouling
Seychelles	AIS	Yes	Ballast & Biofouling
Singapore	AIS	Yes	Ballast & Biofouling
American Samoa	Caribbean	Yes	-
Anguilla	Caribbean	Yes	Lionfish
Antigua & Barbuda	Caribbean	Yes	<i>Halophila</i> Seagrass, Lionfish, Sun Coral
Aruba	Caribbean	Yes	Lionfish
Bahamas	Caribbean	Yes	Asian Green Mussel, Lionfish
Barbados	Caribbean	Yes	<i>Halophila</i> Seagrass, Lionfish, Sun Coral
Belize	Caribbean	Yes	Black Tiger Prawn, Lionfish
Bermuda	Caribbean	Yes	Lionfish
British Virgin Islands	Caribbean	Yes	Lionfish
Cayman Islands	Caribbean	Yes	Lionfish
Cuba	Caribbean	Yes	Asian Green Mussel
Curacao	Caribbean	Yes	Lionfish
Dominica	Caribbean	Yes	<i>Halophila</i> Seagrass, Lionfish, Sun Coral

Dominican Republic	Caribbean	Yes	Asian Green Mussel, Lionfish
Grenada	Caribbean	Yes	<i>Halophila</i> Seagrass, Lionfish, Sun Coral
Guadeloupe	Caribbean	Yes	Aquatic invasive species in General
Guyana	Caribbean	Yes	Aquatic invasive species in General
Jamaica	Caribbean	Yes	Asian Green Mussel, Lionfish
Martinique	Caribbean	Yes	Aquatic invasive species in General
Montserrat	Caribbean	Yes	Lionfish
Saint Lucia	Caribbean	Yes	Asian Green Mussel, <i>Halophila</i> Seagrass, Lionfish, Sun Coral
Sint Maarten	Caribbean	Yes	Lionfish
St Kitts & Nevis	Caribbean	Yes	<i>Halophila</i> Seagrass, Lionfish, Sun Coral
St Vincent & the Grenadines	Caribbean	Yes	<i>Halophila</i> Seagrass, Lionfish, Sun Coral
Suriname	Caribbean	Yes	-
Trinidad & Tobago	Caribbean	Yes	Asian Green Mussel, Lionfish
Turks & Caicos Islands	Caribbean	Yes	Lionfish
Cook Islands	Pacific	Yes	Ballast Water
Micronesia Federated States of	Pacific	Yes	Aquatic invasive species in General
Fiji	Pacific	Yes	Ballast & Biofouling
French Polynesia	Pacific	Yes	Aquatic invasive species in General
Kiribati	Pacific	Yes	-
Marshall Islands	Pacific	Yes	-
Nauru	Pacific	Yes	-
New Caledonia	Pacific	Yes	Aquatic invasive species in General
Niue	Pacific	Yes	-

Palau	Pacific	Yes	-
Papua New Guinea	Pacific	Yes	-
Samoa	Pacific	Yes	-
Solomon Islands	Pacific	Yes	Crown of thorns (native invasive)
Timor-Leste	Pacific	Yes	<i>Lutjanus kasmira</i>
Tonga	Pacific	Yes	-
Tuvalu	Pacific	Yes	-
Vanuatu	Pacific	Yes	Aquatic invasive species in General

Table 4.4 *Small Island Developing States that have ratified the Ballast Water Management Convention (International Maritime Organization 2025a). Ratification indicates that a country has formally approved and committed to implementing the Convention’s requirements under international law.*

UN Atlantic, Indian Ocean and South China Sea SIDS (8)	Ratified	Not Ratified
Cabo Verde		X
Comoros		X
Guinea-Bissau		X
Maldives	X	
Mauritius		X
Sao Tomé and Príncipe		X
Seychelles	X	
Singapore	X	
UN Caribbean SIDS (16)	Ratified	Not Ratified
Antigua and Barbuda	X	
Bahamas	X	
Barbados	X	
Belize		X
Cuba		X
Dominica		X
Dominican Republic		X
Grenada	X	
Guyana	X	
Haiti		X
Jamaica	X	
Saint Kitts and Nevis	X	
Saint Lucia	X	
Saint Vincent and the Grenadines		X
Suriname		X
Trinidad and Tobago	X	
UN Pacific SIDS (15)	Ratified	Not Ratified
Cook Islands	X	
Fiji	X	
Kiribati	X	
Marshall Islands	X	
Micronesia (Federated States of)		X

Nauru		X
Niue	X	
Palau	X	
Papua New Guinea		X
Samoa		X
Solomon Islands		X
Timor-Leste		X
Tonga	X	
Tuvalu	X	
Vanuatu		X
SIDS OF NON-UN /ASSOCIATE MEMBERS (18)	Ratified	Not Ratified
American Samoa (US territory)		X
Anguilla (British Overseas Territory)		X
Aruba (A constituent country of the Kingdom of the Netherlands)		X
Bermuda (British island territory in the North Atlantic Ocean)		X
British Virgin Islands (British overseas territory)		X
Cayman Islands (British overseas territory)		X
Commonwealth of Northern Marianas (U.S. commonwealth in the Pacific Ocean)		X
Curacao (A constituent country of the Kingdom of the Netherlands)		X
French Polynesia (An overseas collectivity of France)		X
Guadeloupe (A French overseas region)		X
Guam (A U.S. island territory in Micronesia)		X
Martinique (An overseas region of France)		X
Montserrat (A British Overseas Territory in the Caribbean)		X
New Caledonia (A French territory comprising dozens of islands in the South Pacific)		X
Puerto Rico (A Caribbean island and unincorporated U.S. territory)		X
Sint Maarten (part of the Kingdom of the Netherlands)		X
Turks and Caicos Islands (A British Overseas Territory)		X
U.S. Virgin Islands (A group of Caribbean islands and islets. A U.S. territory)		X

4.3.3.1 Invasive species management focus across region

Fisher's Exact Test indicated a statistically significant difference across regions ($p = 0.00223$, two-sided), suggesting that invasive species management focus differed significantly across regions.

4.3.3.2 Invasive species management focus for each region

Due to the small sample sizes available for within-region comparisons (e.g., AIS $n = 6$), Figure 4.8 presents raw frequency counts to descriptively illustrate the distribution of invasive species management focus. Across the three regions, all SIDS had a terrestrial invasive species management focus, while the extent to which MIS were also addressed varied regionally (Figure 4.8). All SIDS of the AIS region ($n = 6$) had terrestrial management programmes, and 66.7% ($n = 4$) also incorporated a marine focus. In the Caribbean region ($n = 27$), nearly all SIDS (92.6%, $n = 25$) included both terrestrial and marine invasive species management, with only two countries (7.4%) maintaining a terrestrial-only focus. In the Pacific region ($n = 17$), all SIDS had terrestrial management, but fewer (47.1%, $n = 8$) extended this to include MIS. Overall, terrestrial management remains universal among SIDS, whereas marine biosecurity integration is less consistent, particularly in the Pacific and AIS regions. MIS management tends to be species-specific and limited, with only partial adoption of broader pathway- or system-based approaches such as ballast water or biofouling control (Table 4.3).

4.3.4 Challenges and barriers in managing ship biofouling

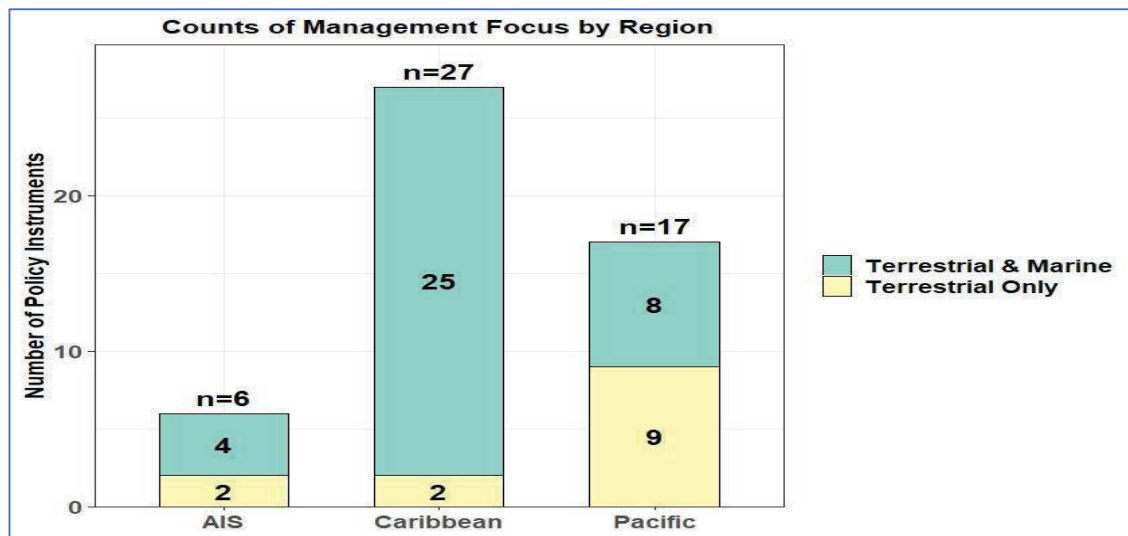


Figure 4.8 Number of Small Island Developing States in each region classified by whether their management focus includes marine invasive species in addition to terrestrial management. AIS represents the Atlantic, Indian Ocean and South China Sea Region.

Challenges identified from the survey, interviews, and document analysis included: Focus on Terrestrial Invasives, Lack of Legislative & Institutional Frameworks, Lack of Knowledge & Expertise, Lack of Financial Resources, Lack of Equipment & Technology, Data Scarcity, Limited Workforce, Lack of Political Commitment & Enforcement, Multisectoral, Jurisdictional Dependency, Unmanaged Points of Entry, Language Barrier, Climate Change, Damage Not Visible Straight Away, and No Standardised Mandatory Measures.

For statistical analysis, only the main challenges, those with a marginal total greater than 10, were retained. These included: *Data Scarcity*, *Focus on Terrestrial Invasives*, *Lack of Equipment & Technology*, *Lack of Financial Resources*, *Lack of Knowledge & Expertise*, *Lack of Legislative & Institutional Frameworks*, *Lack of Political Commitment & Enforcement*, *Limited Workforce*, and *Multisectoral*.

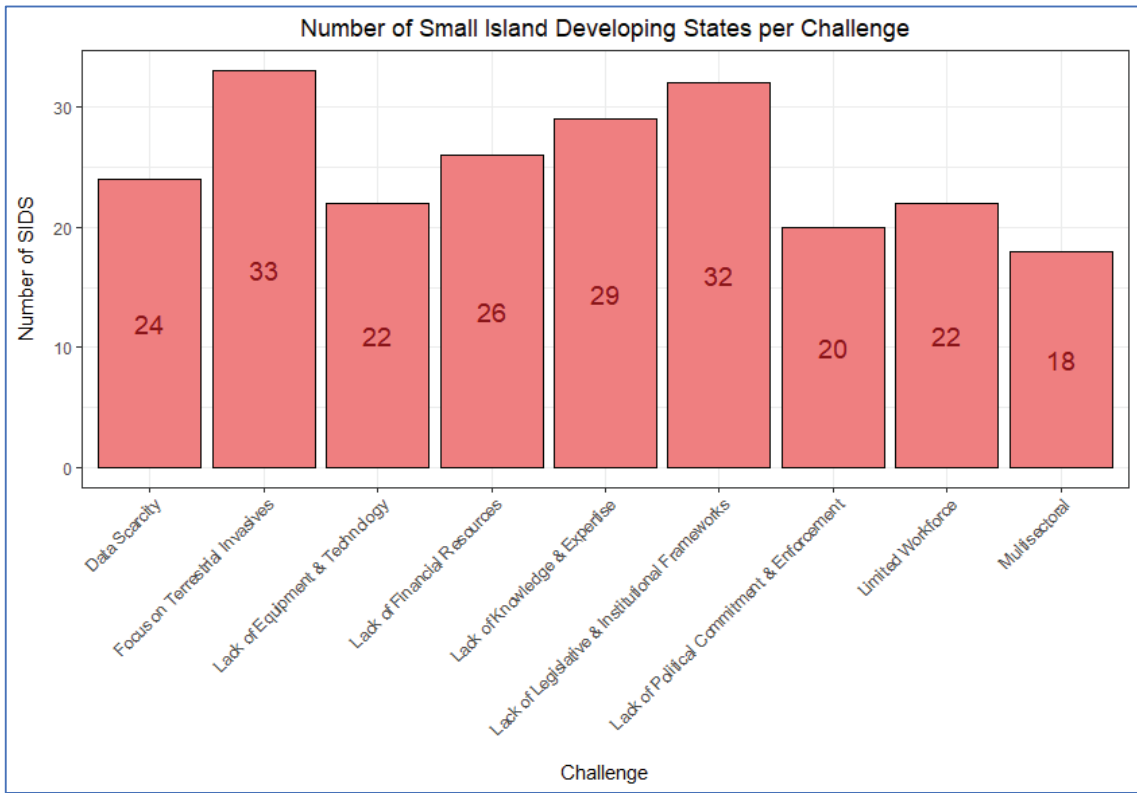


Figure 4.9 Number of Small Island Developing States classified by the main challenges they face in managing ship biofouling.

Among the small island developing states, the most frequently identified challenges in managing biofouling were *Focus on Terrestrial Invasives* (n = 33), *Lack of Legislative & Institutional Frameworks* (n = 32), and *Lack of Knowledge & Expertise* (n = 29). Other challenges recorded included *Lack of Financial Resources* (n = 26), *Data Scarcity* (n = 24), and *Lack of Equipment & Technology* (n = 22),

Limited Workforce (n = 22), *Lack of Political Commitment & Enforcement* (n = 20), and *Multisectoral Coordination* (n = 18) (Figure 4.9). Overall, these results indicate that a wide range of challenges were commonly identified across SIDS, with relatively small differences in the number of countries reporting each category.

4.3.4.1 Challenges and barriers across regions

Fisher's Exact Test indicated no statistically significant difference in main challenges across regions ($p = 0.632$, two-sided), suggesting that main challenges were similar among the three geographic regions.

4.3.4.2 Challenges and barriers for each region

Due to the small sample sizes available for within-region comparisons (e.g., AIS n = 5), Figure 4.10 presents raw frequency counts to descriptively illustrate the distribution of main challenges. In the AIS region (n = 5), the most frequently recorded challenges were Lack of Legislative & Institutional Frameworks (5 SIDS), Data Scarcity (4), Lack of Knowledge & Expertise (4), and Multisectoral Coordination (4). In the Caribbean region (n = 25), the most common challenges were Focus on Terrestrial Invasives (n = 24), Lack of Legislative & Institutional Frameworks (20), Lack of Knowledge & Expertise (19), and Lack of Equipment & Technology (19), while in the Pacific region (n = 13), the most recorded challenges were Lack of Legislative & Institutional Frameworks (7), Focus on Terrestrial Invasives (7), Lack of Knowledge & Expertise (6), Data Scarcity (6) and Lack of Financial Resources (6). The results tell us that across all three regions, Lack of Legislative & Institutional Frameworks and Lack of Knowledge & Expertise were consistently the most frequently recorded challenges among SIDS and illustrate both the within-region distribution and the cross-region patterns of biofouling management challenges have large gaps in their policies.

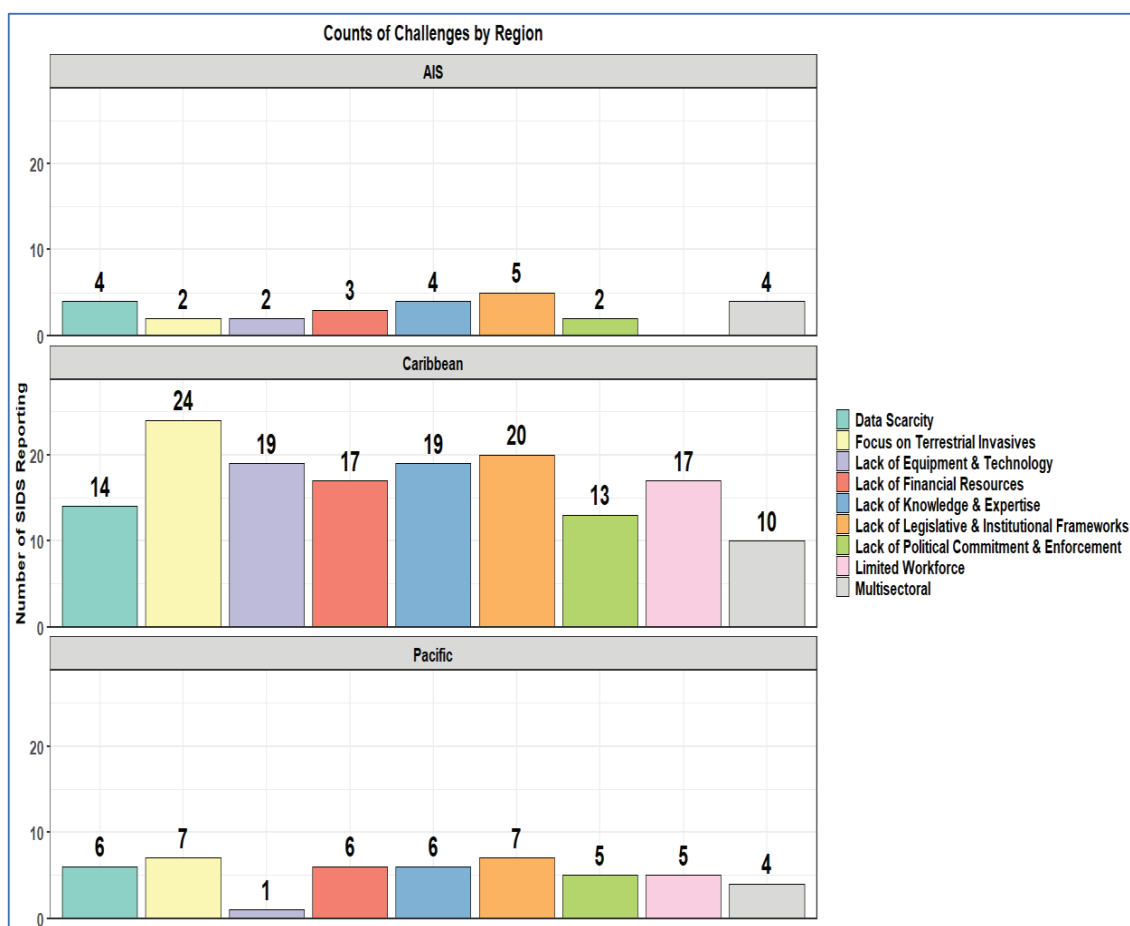


Figure 4.10 Number of Small Island Developing States in each region classified by the main challenges they face in managing ship biofouling. AIS SIDS (n = 5), Caribbean SIDS (n = 23) and Pacific SIDS (n = 15). AIS represents the Atlantic, Indian Ocean and South China Sea Region.

4.3.5 Needs for effective ship biofouling management

Needs identified from the survey, interviews, and document analysis included: Global effort, Data collection, Technical Infrastructure (tools, platforms, and supporting systems), Financial Support, Technical Capacity, Regulatory and Legislative Framework, Human Resources, Lead Agency and Stakeholder Coordination and Political Commitment and Enforcement.

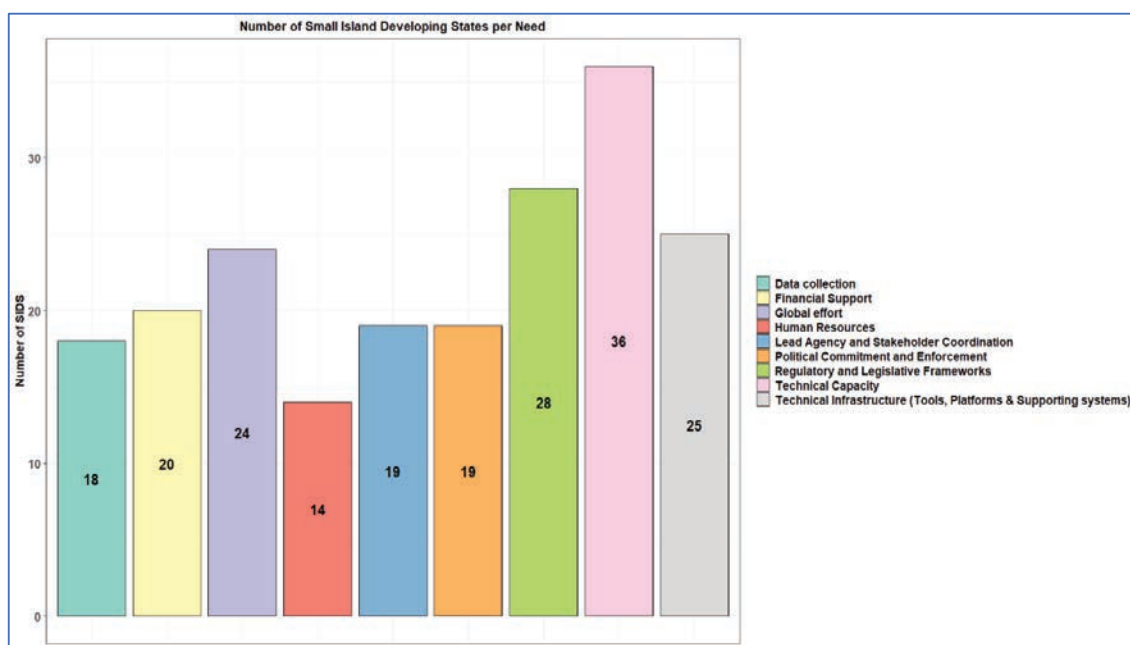


Figure 4.11 Number of Small Island Developing States classified by the main needs identified for managing ship biofouling.

Among the Small Island Developing States, the most frequently identified needs for managing biofouling were Technical Capacity ($n = 36$), Regulatory and Legislative Frameworks ($n = 28$), Technical Infrastructure ($n = 25$) and Global Effort ($n = 24$). Other needs recorded included Financial Support ($n = 20$), Political Commitment and Enforcement ($n = 19$), Lead Agency and Stakeholder Coordination ($n = 19$), Data Collection ($n = 18$), and Human Resources ($n = 14$) (Figure 4.11). Overall, these results indicate that a broad range of needs were commonly identified across SIDS, with some variation in the number of countries reporting each category.

4.3.5.1 Needs across region

Fisher's Exact Test indicated no statistically significant difference in main challenges across regions ($p = 0.9905$, two-sided), suggesting that needs were similar among the three geographic regions.

4.3.5.2 Needs for each region

Due to the small sample sizes available for within-region comparisons (e.g., AIS $n = 5$), Figure 4.12 presents raw frequency counts to descriptively illustrate the distribution of identified needs. In the AIS region ($n = 5$), the most frequently recorded needs were Technical Capacity (4 SIDS) and Regulatory and Legislative Frameworks (4). In the Caribbean region ($n = 25$), the most identified needs were

Technical Capacity (20) and Technical Infrastructure (16), while in the Pacific region (n = 13), the most frequently recorded needs were Technical Capacity (12) and Regulatory and Legislative Frameworks (11).

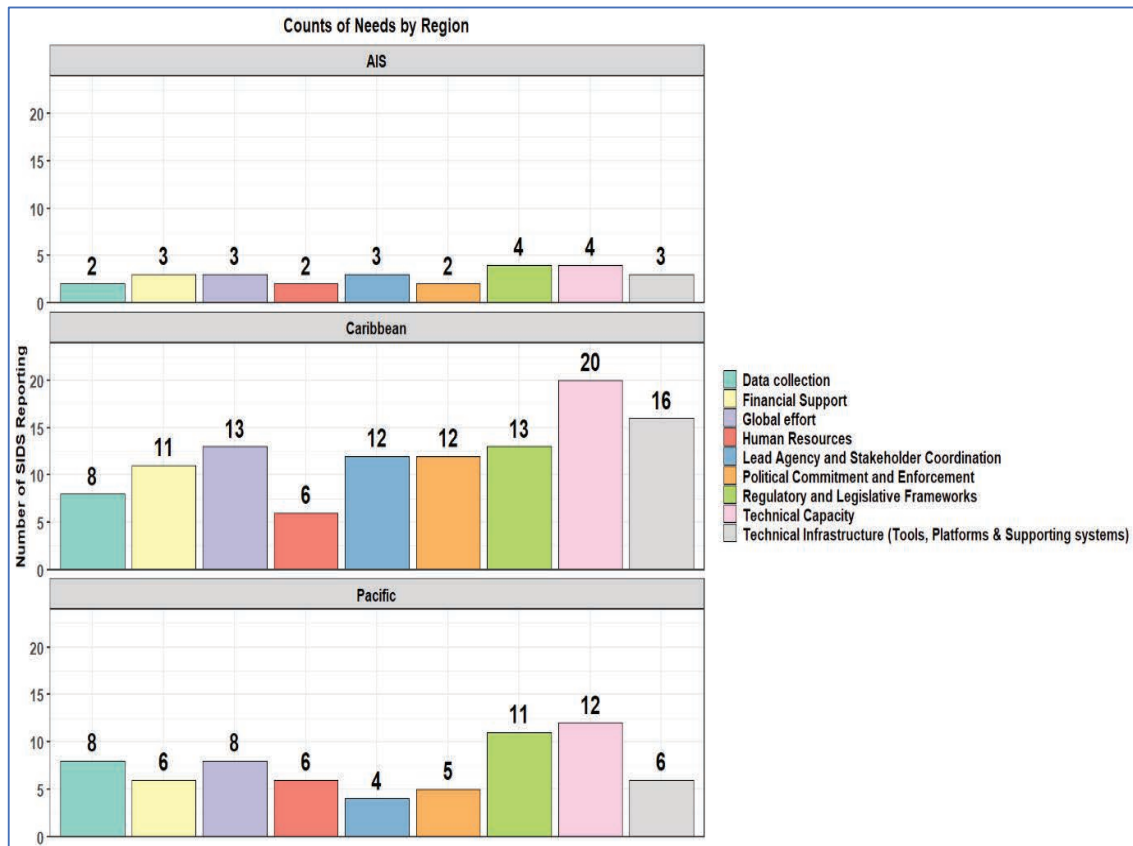


Figure 4.12 Number of Small Island Developing States in each region classified by the main needs identified for managing ship biofouling. AIS SIDS (n = 5), Caribbean SIDS (n = 25) and Pacific SIDS (n = 13). AIS represents the Atlantic, Indian Ocean and South China Sea Region.

Overall, this study has shown the following:

- Awareness level was similar across the three geographic regions, with only 50% of SIDS demonstrating a good awareness of ship biofouling as a vector and threat. However, differences in awareness were observed within the regions. Most Pacific and AIS SIDS showed good awareness, while Caribbean SIDS showed more variable awareness levels, with more countries having no awareness.
- Ship biofouling management status was also similar across the three geographic regions but showed variation within them. Pacific and Caribbean SIDS have a higher proportion of indirect

measures, whereas AIS SIDS showed a relatively higher uptake of direct measures, despite the smaller number of countries represented.

- The focus of invasive species management differed across regions. While most SIDS prioritised terrestrial invasive species, 74% also addressed MIS. However, Marine management efforts were largely limited to a small number of well-known species, including lionfish (*Pterois volitans*), Halophila seagrasses, sun corals (*Tubastraea spp.*), and the Asian green mussel (*Perna viridis*). Caribbean SIDS tended to adopt a species-specific approach to MIS management, Pacific SIDS focused more broadly on aquatic invasive species, and AIS SIDS employed wider pathway-based approaches. Overall, management approaches for marine invasives were predominantly species-specific, with limited implementation of broader pathway- or system-based approaches such as ballast water or biofouling management.
- Regions with higher awareness (AIS) tend to implement broader, system-focused management, whereas regions with lower awareness (Caribbean) focus primarily on species-specific measures (Table 4.5).
- A wide range of challenges were identified across all three regions, with relatively small differences in the number of countries reporting each category. The most frequently reported challenges across regions were a focus on terrestrial invasives, lack of legislative and institutional frameworks, and lack of knowledge and expertise. In addition to these shared challenges, AIS SIDS reported data scarcity and multisectoral governance challenges, Caribbean SIDS reported limitations in equipment and technology, and Pacific SIDS reported data scarcity and limited financial resources.
- A similarly broad range of needs was identified across SIDS, with some regional variation. The most reported needs included technical capacity, regulatory and legislative frameworks, technical infrastructure, and enhanced global effort. AIS SIDS and Pacific SIDS also highlighted the need for stronger regulatory and legislative frameworks, while Caribbean SIDS emphasised improved technical infrastructure.

Table 4.5 *Comparison of awareness and management approaches across regions.*

Small Island Developing States	Awareness (Figure 4.4)	Indirect measures (Figure 4.6)	Direct measures (Figure 4.6)	MIS management focus (Table 4.3)
AIS	High	Low	High	broader pathway- or system-based approach
Pacific	Medium	Medium	Medium	General aquatic species focus and a few broader pathway approach
Caribbean	Low	High	Low	Species-specific

4.4 Discussion

In the absence of a binding international instrument for managing ship biofouling, SIDS remain vulnerable to MIS that cause significant environmental and socio-economic impacts. Consequently, SIDS must be adequately prepared to address this challenge. According to Schneider, Karen et al. (2020), preparedness in a robust biosecurity system depends on being aware of risks, equipped with appropriate resources, capable of timely response, and adaptive to changing circumstances. This study provides an integrated overview of awareness levels, management approaches, and constraints related to capacity (quantity of resources) and capability (quality of resources) in ship biofouling and MIS management across SIDS and examines the implications of these findings for strengthening marine biosecurity through policy, governance, and future management efforts.

4.4.1 Awareness of ship biofouling as an introduction pathway and threat

According to Militzer et al. (2023) “awareness and engagement” are essential elements of an effective biosecurity system. Therefore, the level of awareness of ship biofouling as both an introduction pathway and a threat represents a fundamental indicator of biosecurity system preparedness in SIDS. It constitutes the first step in addressing ship biofouling risks where participants (e.g. governments, industries, NGOs, public) in the biosecurity systems need to observe and identify risks (Aware stage) to prepare for sudden incursions. This process corresponds to the anticipation stage, where risks are recognised before impact (Duchek 2020; Edith et al. 2024). Continuous identification, assessment, and prioritisation of both current and emerging risks are therefore critical to building a resilient biosecurity system (Schneider, Karen et al. 2020).

The findings indicate limited recognition of ship biofouling as an introduction pathway and threat. Although, awareness level was similar across the three geographic regions, only 50% of the SIDS had a good awareness of ship biofouling as a vector and threat, while 34 % had no awareness. Considerable variability was observed within regions: most AIS (83%) and Pacific (64%) SIDS showed good awareness, while Caribbean SIDS had a wider variation in awareness level with more islands having no awareness (48%). This shows a critical vulnerability for SIDS, as low or absent awareness inevitably acts as a foundational barrier, impeding the initial recognition and subsequent prioritisation of biofouling risk necessary for implementing effective countermeasures. This, in turn, compromises the ability of stakeholders (decision-makers, industry, and the public) to proactively address marine invasion risks (Anand 2018; Brasier 2008; Militzer et al. 2023; Outhwaite 2010; Schneider, Karen et al. 2020).

4.4.2 Ship biofouling management status and invasive species management focus in Small Island Developing States

Preparedness involves ensuring that adequate mechanisms such as plans, tools, agreements, and institutional arrangements are in place to manage risks during routine and emergency circumstances (Bland, L.M. et al. 2024; Edith et al. 2024; Schneider, Karen et al. 2020). The ship biofouling management status assessed in this study indicates the extent to which SIDS are equipped to move beyond mere awareness into the “Prepared stage” of a resilient biosecurity system.

The results showed that ship biofouling management status was similar across the three geographic regions but showed variation within them. Overall, 38% of SIDS had no specific ship biofouling management measures, although they implemented measures such as Marine Notices or Regulations related to Anti-Fouling Systems and unofficial biofouling record keeping which partially address biofouling risks. In contrast, 34% had some form of direct ship biofouling management measures in place, primarily focused on hull cleaning. Most countries prohibited hull cleaning in their territorial and port waters or where permitted, required capture systems with risk assessments, permits and reporting. Indirect measures were more common in Pacific and Caribbean SIDS, whereas AIS SIDS implemented more direct measures, despite the smaller number of countries represented.

These results show that while some progress has been made toward preparedness, biofouling management across SIDS remains largely incidental and fragmented. The predominance of indirect mechanisms suggests limited institutional capacity and policy prioritisation, constraining the development of proactive and coordinated frameworks. Such reliance on general anti-fouling regulations, rather than specific biofouling management measures, underscores the broader challenge of translating awareness into operational readiness. This pattern aligns with observations by Anand (2018), who showed that persistent governance and resource constraints such as limited technical

expertise, funding, and enforcement capabilities, in developing countries often limit the effectiveness of marine biosecurity systems..

This insufficient specificity is further contextualised by the analysis of Management Focus. The results showed that the focus of invasive species management differed across regions ($p < 0.05$) with most SIDS prioritising terrestrial invasive species, while the integration of marine biosecurity was less consistent in the Pacific and AIS regions. Management approaches for MIS were predominantly species-specific, with limited implementation of broader pathway- or system-based approaches such as ballast water or biofouling management (Table 4.3). Moreover, regions with higher awareness (AIS) tend to implement management approaches that targeted broader, system- or pathway-level sources of the issue, such as ballast water and ship biofouling. In contrast, regions with lower awareness (Caribbean) predominantly implemented reactive, species-specific management measures (Table 4.5). This pattern is consistent with previous studies (Hixon et al. 2016; McGuire and Hill 2021; Morris 2012), which document that management actions targeting lionfish (*Pterois volitans*), one of the most damaging marine fish invasions globally, were initiated only after ecological and economic impacts had become evident. This demonstrates that SIDS which recognised the importance of addressing the source of the issue implemented proactive measures, whereas those lacking such awareness relied on reactive measures implemented only after damage had become evident and consequential.

According to Waage and Mumford (2008), traditional biosecurity historically emphasised plant and animal health related to agriculture and livestock. These results show that maritime biosecurity, exemplified by ship biofouling, remains largely underregulated globally, contributing to regulatory gaps that particularly impact vulnerable areas like SIDS. The limited and inconsistent focus on biofouling as a distinct marine invasion pathway constrains the development of an integrated biosecurity framework that manages risks across the pre-border, border, and post-border continuum. Further evidence of this limited attention is reflected in the ratification status of the Ballast Water Management Convention (2004), with only 35% of SIDS having ratified it (Table 4.4), underscoring the relatively low adoption of international frameworks targeting key marine invasion pathways. Previous studies (Bland, L.M. et al. 2024; Schneider, K. and Arndt. 2020) have demonstrated that addressing major introduction pathways, rather than individual species, is also a more cost-effective and sustainable approach to reducing invasion risks. Building on these findings, prioritising major introduction pathways provides a practical and scalable strategy for addressing fragmented biofouling management and enhancing marine biosecurity in resource-limited countries such as SIDS.

4.4.3 Challenges, barriers and needs in managing ship biofouling

The overall health of a biosecurity system depends on the quantity and quality of resources, which are critical for organisational and system performance (Schneider, Karen et al. 2020). Challenges and barriers are the observed gaps or shortcomings in resources or operational processes, while needs are the required inputs, capabilities, and strategic directives necessary to close those gaps and achieve intended biosecurity outcomes (Arndt, Edith 2024).

The study showed that the distribution of main challenges and needs did not differ significantly across regions, indicating that these constraints and needs are widespread and systemic rather than region-specific, with relatively small differences in the number of countries reporting each category. The results here from the analysis of challenges, barriers, and needs reveals that the management of MIS via ship biofouling in SIDS are constrained by consistent deficiencies in resource quantity and quality (e.g., funding, technical expertise, infrastructure), and persistent governance issues (weak institutions, poor coordination, or limited enforcement capacity) (Table 4.6), highlighting systemic structural weaknesses common in developing countries. These challenges and needs align directly with the key organisational inputs required for a healthy biosecurity system: Capacity (quantity of resources) and Capability (quality of resources) as shown in Edith et al. (2024) and Schneider, K. and Arndt. (2020).

Table 4.6 Key challenges and needs in SIDS ship biofouling management.

Challenges	Needs
Focus on Terrestrial Invasives	Global effort
Data Scarcity	Data collection
Lack of Equipment & Technology	Technical Infrastructure (Tools, Platforms & Supporting systems).
Lack of Financial Resources	Financial Support
Lack of Knowledge & Expertise	Technical Capacity
Lack of Legislative & Institutional Frameworks	Regulatory and Legislative Frameworks,
Lack of Political Commitment & Enforcement	Political Commitment and Enforcement,
Limited Workforce	Human Resources
Multisectoral	Lead Agency and Stakeholder Coordination

Edith et al. (2024) and Schneider, K. and Arndt. (2020) have shown that capacity and resource deficiencies compromise the core inputs of the biosecurity system, hindering its ability to be robustly resourced. Accordingly, strengthening marine biosecurity systems in SIDS requires addressing the high

frequency of challenges identified in this study, which broadly compromise preparedness. This entails implementing the corresponding needs identified by SIDS' stakeholders. For example, challenges such as lack of financial resources, limited workforce, and lack of equipment and technology, necessitates the provision of financial support, securing human resources, and the acquisition of technical infrastructure.

In addition to resource quantity, biosecurity systems require quality resources. In the case of SIDS, the frequently identified lack of knowledge and expertise will inhibit the system's capability. This challenge corresponds directly to the identified technical capacity need. As highlighted in previous studies (Anand 2018; Bland, L.M. et al. 2024; Edith et al. 2024; Li and Yu 2023; Militzer et al. 2023; Outhwaite 2010; Ricciardi et al. 2021; Schneider, Karen et al. 2020), addressing this challenge requires specialist training, expertise, and taxonomic skills for conducting risk assessment, early detection, monitoring, and rapid response. Sound biosecurity planning also requires comprehensive and timely data collection, collation, and analysis (Edith et al. 2024; Schneider, Karen et al. 2020), an area that SIDS must strengthen given the widespread data scarcity observed. Consequently, improving the ability of SIDS to anticipate and prioritise risks effectively will depend on strengthening their data collection and management systems to overcome this constraint.

Furthermore, pervasive institutional and governance deficiencies undermine the structural integrity needed for effective management, highlighting biosecurity as a complex, often fragmented, policy problem (Bahamas Environment 1999; Bland, L.M. et al. 2024; Chase et al. 2011; DeFries and Nagendra 2017; Government of Antigua and Barbuda. Department of Environment 2023a; Head 2008; Mahot 2014; Reaser 2013; Vaas et al. 2017). In many regions, the legal framework is ill-equipped to tackle modern biosecurity challenges, requiring significant institutional reform (Anand 2018; Bland, L.M. et al. 2024; Schneider, Karen et al. 2020).

The findings showed that SIDS similarly face significant institutional and governance constraints including the absence of dedicated legislative and institutional frameworks, limited political commitment and enforcement capacity, and weak multisectoral coordination. Addressing these governance gaps will require strengthening regulatory and legislative frameworks, securing sustained political commitment and enforcement, and establishing a lead agency. Improved stakeholder coordination across multiple actors, including governmental, industrial, and community stakeholders is also essential to clarify roles and responsibilities and to support the effective implementation of prevention and response strategies.

Finally, the predominance of terrestrial invasives focused management highlights that marine pathways, including ship biofouling, remain a lower priority in SIDS. This narrow focus limits the adoption of integrated, pathway-based biosecurity measures, which are widely recognised as more cost-effective and sustainable than species-specific interventions. This misalignment, combined with the current

absence of binding international instruments for ship biofouling, enforces the identified need for a global effort to implement standardised mandatory measures addressing the biosecurity source. These interconnected needs are essential to strengthening the foundational capacity and capability of SIDS to withstand the constant pressures of global trade and environmental change.

4.5 Conclusion

In the absence of binding instruments that provide the first line of defence, SIDS must protect themselves against MIS introductions via the high-risk pathway of ship biofouling. However, as discussed in previous chapters, addressing MIS requires substantial efforts and resources, which many resource-limited countries like SIDS, lack. The analysis conducted in Chapter 4 is significant, as it provides the critical foundational data to inform the development of targeted strategies that can close regulatory gaps and strengthen marine biosecurity in SIDS. This study assessed the preparedness of SIDS in managing the introduction of MIS via ship biofouling by assessing five key aspects: awareness of biofouling as a vector and threat, current ship biofouling management status, the invasive species management focus, the challenges and barriers encountered and the needs for effective ship biofouling management. By synthesising information from national measures and stakeholder perceptions across these dimensions, this study provides an integrated perspective on how SIDS are currently addressing marine biosecurity risks, highlighting both areas of progress and persistent gaps within their marine biosecurity system.

The findings revealed that the preparedness of SIDS to manage MIS via ship biofouling is widely compromised. There was a failure to perceive the severity of biofouling risks as only 50% of SIDS had a good awareness. Ship biofouling management across SIDS was incidental and fragmented with indirect measures being predominant, whereas terrestrial invasive species management remained universal. Overall, SIDS had limited capacity and capability for managing ship biofouling effectively. This showed that SIDS were not aware, prepared, resourced, responsive and adaptive to protect themselves. SIDS preparedness is compromised by challenges like focus on terrestrial invasives, lack of legislative and institutional frameworks, lack of knowledge and expertise, data scarcity, lack of equipment and technology, multisectoral and lack of financial resources, lack of political commitment and enforcement and limited workforce.

Addressing these challenges will require a multi-faceted approach, including strengthening legislative and institutional frameworks, building technical capacity, improving data collection systems, securing sustainable physical, financial and human resources, and promoting cross-sectoral collaboration (Figure 4.13). Effective MIS management requires developing national prevention capabilities, and applying the precautionary principle with improved, evidence-based decision tools (Li and Yu 2023; Simberloff 2005). Importantly, focusing on pre-border measures and major introduction pathways rather than

individual species will enable SIDS to implement more integrated, cost-effective, and resilient biosecurity systems, ultimately reducing ecological and economic impacts associated with marine invasions. Building on this, the next chapter explores how lessons from Australia, which has already established robust pre-border measures to anticipate and prevent MIS and biofouling risks, can guide SIDS in strengthening their capacity and capability in managing ship biofouling and MIS more broadly.

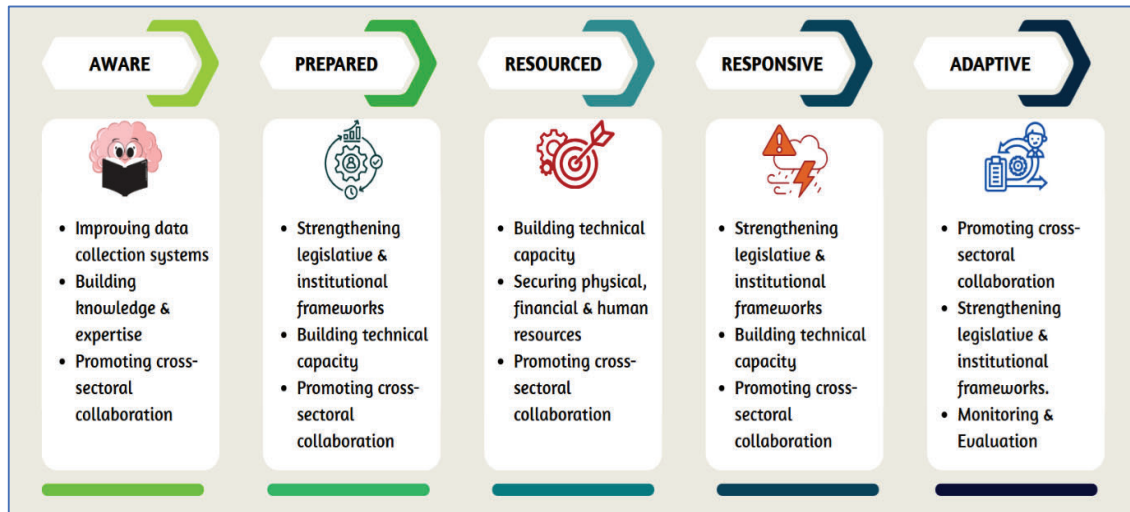


Figure 4.13 Recommendations to enhance biosecurity system resilience across the five capacity domains, *Aware, Prepared, Resourced, Responsive, and Adaptive* for SIDS, adapted from Schneider et al. (2020). *Aware* refers to the ability to anticipate biosecurity risks; *Prepared* to being ready to detect incursions; *Resourced* to having the capacity and capability to support biosecurity risk management; *Responsive* to responding quickly and effectively to incursions; and *Adaptive* to recovering from incursions and adjusting to new circumstances through continuous monitoring and evaluation of system performance.

The research in Chapter 4 is profoundly significant because it empirically established that the extensive capacity and capability deficiencies across SIDS severely compromise their preparedness against ship biofouling risks. Awareness is a fundamental indicator of biosecurity system preparedness, and a critical insight was the finding that higher awareness correlates with the adoption of proactive, system- or pathway-level management, while lower awareness correlates with reactive species-specific approaches, validating the understanding of pursuing resource-efficient, pre-border biosecurity measures over costly border or post-border measures. This foundational diagnosis directly transitions to Chapter 5, which moves from identifying the problem (lack of preparedness of SIDS) to finding a practical solution. Chapter 5 assesses Australia’s established, evidence-based ship biofouling management framework to identify specific, adaptable strategies that SIDS can adapt to address their

identified legislative, technical, and resource gaps. In the overall thesis, Chapter 4 is pivotal because its empirical findings validate the necessity of tailoring solutions to SIDS' severe capacity and capability limitations, thereby reinforcing the overarching aim of the thesis, to shift governance toward mandatory, cost-effective prevention, strengthen resilience, and promote equity in global marine biosecurity.

Chapter 5: Strengthening the capacity of small island developing states to monitor ship biofouling: insights from Australia

5.1 Introduction

As we saw in previous chapters, the preparedness of small island developing states (SIDS) to address marine invasive species (MIS) introduction via ship biofouling is widely compromised due to systemic deficiencies in capacity and capability (Chapter 4). These deficiencies include a lack of legislative and institutional frameworks, scarcity of knowledge and expertise, data scarcity, and lack of financial resources amongst others. Successfully mitigating this continuous threat and strengthening preparedness requires strategies tailored to address SIDS' three critical management priorities: *ecological threats, resource availability, and livelihood implications* (Chapter 3).

Given that these complex, interlinked challenges emerge from interactions across ecological, regulatory, socio-political, and global systems (Figure 1.3), merely improving isolated activities is insufficient (Chew and Hamilton 2011; Colautti and MacIsaac 2004; Essl et al. 2018; Piria et al. 2021; Seebens et al. 2018; Soto et al. 2024; Tarkan et al. 2024). Effective management therefore requires moving away from fragmented, sectoral responses in favour of a holistic and integrated biosecurity system specifically designed to address these core, interconnected challenges (Arthur et al. 2008; Bland, L.M. et al. 2024; Heikkilä 2011; Outhwaite 2010). In this context, this chapter critically evaluates Australia's biosecurity approach to the management of ship biofouling, with the aim of identifying strategies that may be transferable to SIDS.

5.1.1 A Biosecurity system approach to ship biofouling and MIS management

A biosecurity system forms a coordinated set of management activities that adopt an integrated approach to protecting a country's biodiversity, human health, food security, recreational activities, and socio-economic values from the adverse impacts of pests (e.g. MIS), pathogens, and diseases. (Arthur et al. 2008; Bland, L.M. et al. 2024; Heikkilä 2011; Outhwaite 2010). Any biosecurity system needs to provide the structural capacity to address the challenges and complexities of ship biofouling and MIS management. It includes core activities implemented by a range of stakeholders (governments, various industry stakeholders, public, etc.) in the *pre-border, border, and post-border* settings to provide a shield protecting environmental, economic, and social values of the country (Figure 5.1) (Bland, L.M. et al. 2024; Edith et al. 2024). Dealing with ship biofouling and MIS management, which involves interlinked factors, such as environmental complexities and regulatory gaps, requires a systems-based approach. Adopting a biosecurity system's approach to address this issue promotes better alignment across each component of the system, ensuring it operates efficiently with well-managed resources

(Bland, L.M. et al. 2024; Outhwaite 2010; Schneider, Karen et al. 2020). This integrated strategy is crucial for designing a more efficient and effective response to threats, ultimately strengthening resilience and addressing the complex interaction of environmental challenges and regulatory deficiencies (Anand 2018; Edith et al. 2024; Outhwaite 2010).

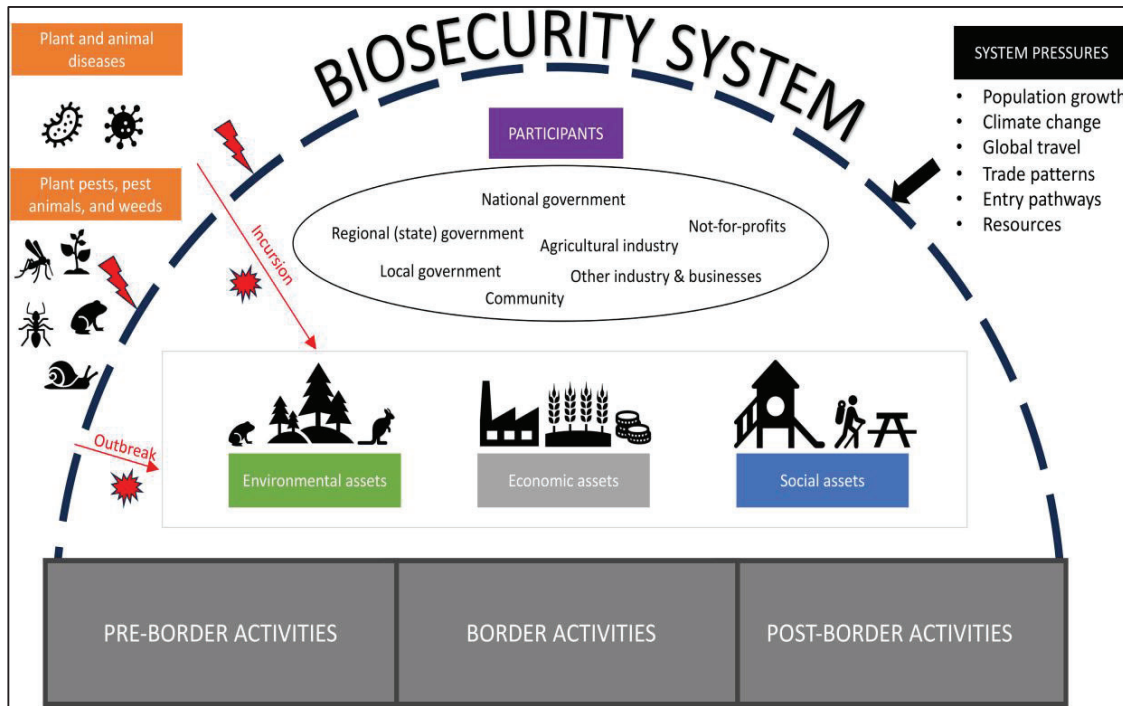


Figure 5.1 Elements of a national biosecurity system, illustrating how management priorities, resources, and system pressures influence the effectiveness of biosecurity and the risk of pests (e.g. marine invasive species), diseases and pathogens establishing and spreading (Edith et al. 2024).

A fully integrated biosecurity system encompasses seven main, sequential, and cumulative activities structured to provide layered defence across the pre-border, border and post-border components. Pre-border and border activities are mainly carried out by the government and the post-border activities require a collaborative approach involving the government, industry, NGOs, producers and the general public (Schneider, Karen et al. 2020). These seven activities include: (1) anticipating biosecurity risks, (2) preventing biosecurity risk material from arriving at the border, (3) screening entry pathways, (4) preparing for incursions or outbreaks, (5) detecting pests (e.g. MIS) and diseases incursions, (6) responding to incursions or outbreaks, and (7) recovering from incursions or outbreaks and adapting to new circumstances (Bland, L.M. et al. 2024; Schneider, Karen et al. 2020).

According to Schneider, Karen et al. (2020), the system begins with anticipating biosecurity risk at the pre-border stage, where risks are systematically identified, analysed, and prioritised via environmental scans, intelligence forums, and offshore monitoring activities. It then focuses on preventing

biosecurity-hazard material from approaching national borders by managing threats offshore via international arrangements and capacity-building initiatives. At the border, entry pathways are screened to detect non-compliance, reducing the likelihood of invasive species introductions through conveyances such as vessels and aircraft. Post-border activities include preparing for potential incursions or outbreaks by building the capacity and capability to respond effectively, detecting invasive species and diseases incursions to enable timely action, and responding to outbreaks through coordinated efforts among governments, industry, and other stakeholders. Finally, the system addresses recovery from incursions or outbreaks and adaptation to new circumstances, with stakeholders implementing short- to long-term measures for relief, recovery, and adaptation.

While the biosecurity continuum details the necessary collaboration among stakeholders and the sequential activities required for risk management, the efficacy of this complex, interconnected structure is continuously challenged by external shocks and pressures, such as increasing trade volumes and climate change. Consequently, the biosecurity system must not only function effectively under normal conditions but also demonstrate resilience in the face of such disruptions. (Bland, L.M. et al. 2024; Edith et al. 2024; Schneider, Karen et al. 2020). The identified enabling factors including human, financial, and physical resources and organisational capabilities directly underpin this resilience, as they constitute the system's capacity and capability (Bland, L.M. et al. 2024; Edith et al. 2024; Schneider, Karen et al. 2020). Without the appropriate quantity and quality of these resources, the biosecurity system cannot achieve lasting effectiveness, resilience, or sustainability. Recognising this, the resilience paradigm offers a framework for strengthening the system's preparedness for impacts of unpredictable, low-likelihood, high-impact incursions (Edith et al. 2024; Schneider, Karen et al. 2020).

Resilience in a biosecurity system is built on five key characteristics: *aware*, understanding the risks and how to address them; *prepared*, with the plans, tools, and surveillance capacity to manage risks under normal and emergency conditions; *resourced*, maintaining sufficient financial, human, physical, and organisational capability; *responsive*, able to act quickly and effectively to contain or eradicate incursions; and *adaptive*, learning from events, adjusting to new conditions, and improving performance through monitoring and evaluation (see Box 12 in Schneider, Karen et al. (2020); Appendix C). For SIDS, addressing the multi-level and systemic deficiencies (lack of resources, inconsistent governance, etc., Chapter 4) requires strategies that specifically enhance these five characteristics. This makes the Anticipate and Prevent stages, which offer higher returns on investment compared to later activities (Screen, Prepare, Detect, Respond, and Recover/Adapt) paramount for these resource-constrained nations (Bland, L.M. et al. 2024; Li and Yu 2023; Simberloff 2005).

5.1.2 Australia as a Case Study for Adaptable Solutions

Australia, alongside Canada, was among the first countries to raise concerns about MIS in the late 1980s at the International Maritime Organization (IMO) and has subsequently accumulated extensive experience spanning three decades in managing MIS risks from ballast water and ship biofouling (Geoff, Taylor and Hallegraeff 2014; Hayes, Inglis and Barry 2019; International Maritime Organization 2025a; Molino, Campbell and Wetherbee 2009; Molino et al. 2009; Piola and McDonald 2012). The quality of Australia’s MIS management strategies is internationally recognised (Awad et al. 2014). Its scientific and technical expertise has been fundamental to international capacity building, informing guides such as the “Guidance on Port Biological Baseline Surveys (PBBS)” in the GEF-UNDP-IMO GloBallast Partnerships Project and in the GEF-UNDP-IMO GloFouling Partnerships Project (Awad et al. 2014; GEF-UNDP-IMO GloBallast Partnerships Programme 2017; GEF-UNDP-IMO GloFouling Partnerships 2019d). As a result, Australia’s MIS management strategy provides a well-respected foundation for the development of sound strategies that can be adapted to the particular situations prevailing in MIS.

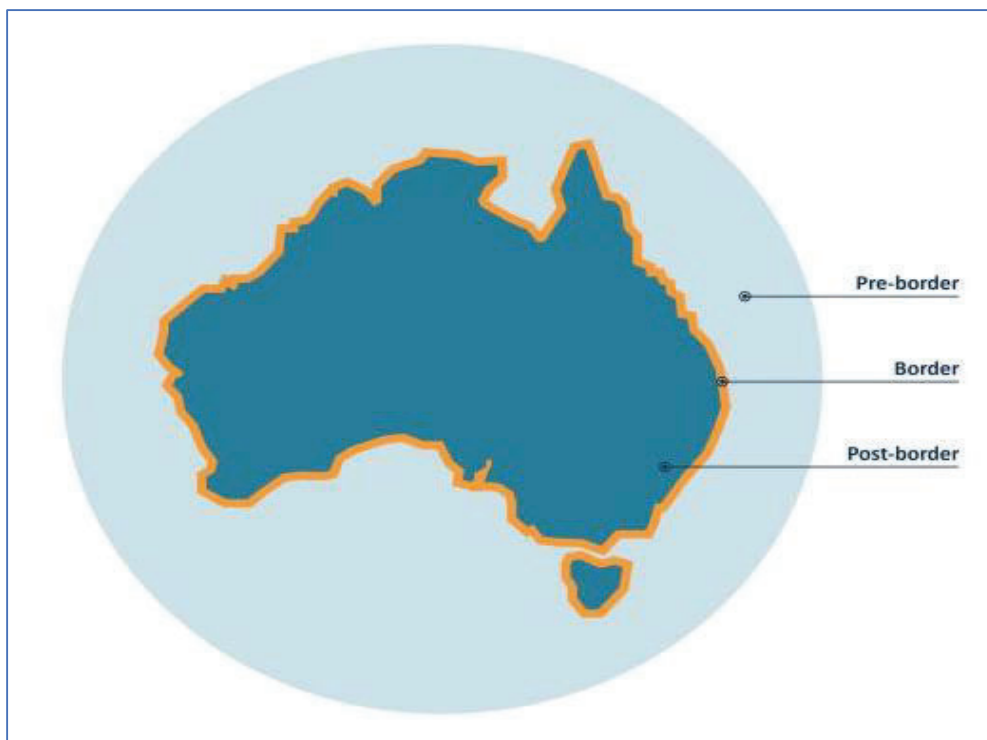


Figure 5.2 Australia’s multi-layered environmental biosecurity system comprises three stages: pre-border measures to prevent invasive species entry through regional and international collaborations, and import controls, border measures including inspections, screening, quarantine, and penalties, and post-border measures to monitor and respond to invasive species and diseases detected within Australia (Department of Agriculture, Fisheries and Forestry, 2024b).

Australia's comprehensive multi-layered biosecurity system (Figure 5.2) is built upon the concept of shared responsibility and rigorous, multi-faceted scientific research that informs proactive risk mitigation strategies (Department of Agriculture 2023; Department of Agriculture, Fisheries and Forestry, 2024b). These studies provide critical technical evidence for tropical SIDS to establish time sensitive effective pre-border management and inform the development of necessary, evidence-based management protocols (Arndt, E et al. 2021; Floerl, Wilkens and Woods 2010; Molino, Campbell and Wetherbee 2009; Molino et al. 2009). As an Island nation that has introduced specific mandatory biofouling regulations alongside New Zealand and the United States, the Australian experience, including its achievements and shortcomings in linking science with policy, offers potential, adaptable solutions for strengthening SIDS' capacity (Alghamdi and Quijada 2019; Hayes, Inglis and Barry 2019). Therefore, the current study analyses Australia's biofouling management measures to identify approaches that could be adapted to strengthen biofouling management capacity of SIDS by documenting and analysing evidence from Australia's national measures and stakeholder perceptions regarding existing biofouling management measures, resources and costs, and adaptability of measures to the financial, institutional, and technical needs and challenges of SIDS.

5.2 Methods

A mixed-methods approach, comprising surveys, interviews, and document analysis, was employed to evaluate Australia's biofouling management measures to identify approaches that could be adapted to strengthen SIDS' biofouling management capacity and capability. Strategies were reviewed and categorised into pre-border, border, and post-border measures to determine effective approaches for managing the introduction of marine invasive species via ship biofouling, with emphasis on their adaptability to Small Island Developing States contexts. As the analysis focused on the types of strategies rather than the volume of documentation, variation in the number of documents across states does not compromise the validity of the thematic assessment.

Survey requests were sent to the biosecurity departments of all Australian states and territories (QLD, NSW, TAS, VIC, SA, WA, NT, ACT and OTHER), 21 port entities, 86 marinas, and 24 industry stakeholders involved in biofouling monitoring and or ship hull cleaning. In total, responses were received from 9 participants from state and territory biosecurity departments (77%), 6 port entities (28%), 7 industry stakeholders (29%) and 3 from marinas (3%). Two responses were also received from international stakeholders engaged in Australia's biosecurity. Due to very low response rates from marinas, their data were excluded from the analysis. The final dataset therefore comprised responses from state and territory biosecurity departments (ACT, WA, NSW, NT, VIC, SA), international stakeholders engaged in Australia's biosecurity (Pacific Community, New Zealand), Queensland ports, the Ports Authority of NSW, and industry stakeholders. Queensland ports achieved a 100% response

rate, allowing for a more meaningful comparison with SIDS, given their shared tropical context. A follow-up interview was conducted only with Queensland ports to clarify certain responses.

To guide this analysis, the following research questions were addressed:

1. What types of management strategies are used in Australia to manage and control the introduction of marine invasive species via ship biofouling?
2. What resources are involved in implementing these strategies (e.g., staff, equipment, etc.)?
3. What are the running costs associated with these strategies?
4. To what extent are these strategies resource-efficient and adaptable to the needs and challenges of SIDS?

Main Themes for research questions one, two and three are:

- **Biosecurity Measures** – Categorises Australia’s marine invasive species and ship biofouling management measures into three components according to the biosecurity system framework outlined by Bland, Lucie M. et al. (2024):
 - o *Pre-border*: Measures for anticipating biosecurity risks and preventing risk materials from arriving at the border.
 - o *Border*: Measures for screening entry pathways to detect non-compliance and minimise risk of entry.
 - o *Post-border*: Measures for detecting incursions of non-indigenous species or diseases, preparing and responding to outbreaks and incursions, and recovering or adapting after outbreaks.
- **Resource Requirements** – Identifies the financial resources, physical resources, human resources and organisational capability needed for implementing pre-border, border, and post-border strategies. These four categories follow the framework of “capacity and capability of the national biosecurity system” outlined in Figure ES 6 of Schneider, Karen et al. (2020).
- **Running costs** – Assesses the financial requirements associated with maintaining pre-border, border, and post-border strategies, including recurring operational expenses.

Outcomes from research questions one, two and three were subsequently used to address question four, evaluating which of Australia’s strategies are most feasible and resource-efficient for adaptation in SIDS, considering their financial, institutional, and technical constraints.

5.2.1 Data collection and analysis

5.2.1.1 Surveys and interviews

Surveys and interviews were conducted under the approval of the JCU Human Research Ethics Committee (H8780).

5.2.1.1.1 Participant details

Participants comprised major decision-makers and stakeholders with first-hand knowledge of fouling MIS management, as this study evaluates Australia's biofouling management measures. They included officials from state and territory biosecurity departments (e.g., Department of Primary Industries Aquatic Biosecurity, NSW; Department of Agriculture, Fisheries and Forestry, SA; Australian Bureau of Agricultural and Resource Economics and Sciences, other), international stakeholders engaged in Australia's biosecurity (Pacific Community, New Zealand), members of Ports Australia, and stakeholders engaged in biofouling surveys and hull cleaning activities. All participants were provided with an information sheet and participation was voluntary, and responses were treated confidentially.

5.2.1.1.2 Sampling strategy

Surveys were sent via email to individual biosecurity departments and to stakeholders involved in biofouling surveys and hull cleaning. Surveys were also distributed to biosecurity departments of states and territories via the Marine Pest Sectoral Committee and to ports across Australia, via Ports Australia. The survey was also advertised in the Australian Coastal Society Newsletter Issue 8 of 1 June 2024.

5.2.1.1.3 Survey administration

Surveys were conducted using Qualtrics, with the 'Prevent multiple submissions' option enabled to flag any duplicate responses. In cases where discrepancies were identified between submissions, participants were contacted via email to provide clarification.

5.2.1.1.4 Interview content and strategy

Participants from Queensland Ports were individually contacted to determine their preference for a one-on-one or focus group interview, as all Queensland Ports are implementing the same monitoring programme in partnership with Biosecurity Queensland. All participants opted for the follow-up focus group interview to clarify some of the survey responses. The interview was planned to last no more than one hour to minimise participant burden and fatigue. Consent was obtained from each participant

in writing, via an informed consent form before proceeding with the Zoom interview. The interview questions were provided in advance to allow participants adequate time for preparation.

5.2.1.1.5 Documentary analysis

Documentary data were collected from materials and websites referenced by survey and interview participants, as well as from relevant Australian Government websites. These documents included national and state policies, regulations, reports, guidelines, and other grey literature relevant to biofouling management and the control of marine invasive species.

The documents were reviewed and categorised according to the thematic framework applied to the survey and interview data, focusing on the pre-border, border, and post-border components of the biosecurity system (Bland, L.M. et al. 2024). This classification enabled the identification of measures across different stages of biosecurity risk management.

The documentary analysis complemented the survey and interview data by identifying the management strategies in practice, the resources required and associated operational costs. This triangulated approach enabled a comprehensive understanding of Australia's ship biofouling management framework and informed the evaluation of strategies most feasible and resource efficient for adaptation in Small Island Developing States.

5.2.1.1.6 Data analysis and ranking strategies

Interview, survey, and documentary data were analysed using NVivo 14, following both inductive and deductive coding techniques. Responses and documents were coded into six main thematic categories: ***pre-border strategies, border strategies, post-border strategies, resource requirements, running costs, and implementation challenges***. To reduce individual-level bias during data extraction and synthesis, the process and findings were reviewed and discussed with my advisory panel and internal colleagues, whose input helped validate the categorisation and ensure consistency and rigour in interpretation.

As this study focused on identifying and evaluating the types of biofouling management strategies, their resource requirements, associated costs and implementation challenges, the analysis was primarily qualitative and descriptive. Data were synthesised through thematic coding and descriptive summaries to identify patterns across stakeholders and jurisdictions. No inferential statistical tests were performed, as the aim was not to test hypotheses or compare groups quantitatively, but rather to determine which strategies are most feasible and resource efficient for adaptation in Small Island Developing States.

To support this, strategies were ranked according to cost-effectiveness, defined by two dimensions:

1. **Resource requirements** – types and quantity of staff, equipment, and institutional support needed.
2. **Running costs** – recurring operational expenses required to sustain the strategy.

Each dimension was categorised as *Low*, *Medium*, or *High*, using the criteria in Table 5.1. Strategies requiring fewer resources and incurring lower operational costs were classified as more cost-effective and feasible for adaptation in SIDS. Those categorised as *Low* in both dimensions were considered the highest-ranking “**best approaches.**”

Table 5.1 *Criteria for ranking cost-effectiveness of Australian biofouling management strategies.*

Criteria	Low	Medium	High
Resource requirements	Minimal staff/equipment; limited institutional support; easy to implement	Moderate staff/equipment; some institutional support; manageable implementation	Extensive staff/equipment; high institutional support; complex implementation
Running costs	Low recurring costs (minimal operational expenses. Example staff salary)	Moderate recurring costs (Example staff salary and costs of specialised tools or labour for routine in-water maintenance requiring)	High recurring costs (Example, staff salary, cost for surveillance, preparedness and response programs).

The application of this ranking framework to Australian strategies is shown in Table 5.4, presenting their classification for resource requirements, running costs, and overall cost-effectiveness.

5.3 Results and discussion

5.3.1 Australian biofouling management system

The analysis of regulatory documents and stakeholder input collected in this study shows that Australia manages the risk of MIS introduction via ship biofouling at the pre-border, border and post-border stages (Figure 5.3 and Table 5.2). The pre-border component of the biofouling management system

requires all vessels, commercial and non-commercial, to submit a mandatory pre-arrival report (PAR) through the Maritime and Aircraft Reporting System (MARS) of the Department of Agriculture, Fisheries and Forestry (DAFF), 90 days to 12 hours before arriving in Australia's territory. Vessel operators and owners use the PAR to inform DAFF which of the three accepted biofouling management options (Table 5.2) are implemented by the vessel. Failure to demonstrate implementation of any of the three accepted options will require vessels to provide additional pre-arrival details. The department uses the information provided in the PAR to make preliminary assessment of biosecurity risks associated with the biofouling management practices of the vessel. Vessel Check is another online biofouling risk assessment tool used by Agriculture Victoria to evaluate incoming vessels' risk and guide management actions.

At the border, verification inspections are conducted to ensure the vessels have implemented the biofouling management measures reported in the PAR. To further reduce the introduction of MIS in Australian waters, different states have restrictions on in-water cleaning activities. For example, in New South Wales, operators may clean and polish propellers in water if macrofouling is absent and a work permit is approved. In-berth removal of macrofouling (and currently microfouling pending policy, personal communication) is prohibited and in-water cleaning is only permitted at sea beyond port limits (Port Authority of New South Wales 2024). Many Queensland ports prohibit in-water hull cleaning or non-urgent repairs with exceptions requiring compliance with Australian anti-fouling and in-water cleaning standards (personal communication). In the Northern Territory, in-water cleaning of international vessels is prohibited (personal communication), while Tasmania allows partial in-water cleaning if the assessed biosecurity risk is low (Department of Natural Resources and Environment Tasmania - Biosecurity Tasmania 2024a, 2024b). Southern Australia only allows in-water cleaning subject to stringent conditions, for which a permit is required (Government of South Australia 2024). In Victoria, in-water cleaning is permitted only when dry docking is not feasible and must use independently tested systems that ensure all biofouling and contaminants are captured and contained to prevent their release, with prior approval from the Harbour Master based on advice from Agriculture Victoria (Agriculture Victoria 2025).

The post-border component consists of surveillance and monitoring programmes at entry points such as ports and marinas, using a mixed-method approach for early detection of MIS (Table 5.2). These efforts are complemented by strategies and response plans to manage incursions. These multi-level biofouling management measures demonstrate that Australia has a comprehensive biofouling management system that integrates risk assessment, vessel inspections, in-water cleaning guidelines, and regulatory oversight.

Australia has undertaken a range of studies to anticipate and prepare for the risks associated with ship biofouling. These studies (Arndt, E et al. 2021; Floerl, Wilkens and Woods 2010; Hewitt et al. 2011; Sherman, Jennings and Miller 2020) include MIS risk analyses that examined the geographical location

of ports and vessel residency times, temporal development of biofouling organisms, factors contributing to vessel biofouling and their relation to biosecurity risk, the risk of MIS introduction, establishment, and spread via biofouling, as well as risks associated with organism release during in-water cleaning and the determination of acceptable filtration levels. Australia has also conducted these pollution risk analyses (Bloomfield 2020; Lewis 2020; Stenekes, Kancans and Binks 2018) focusing on in-water cleaning risk management, chemical concentrations potentially released during cleaning, and antifouling efficiency and performance, as well as studies identifying communication strategies to support pathway risk management.

The system used by Australia has been continuously refined through research, monitoring, and operational experience, providing a proven model for preventing the introduction and spread of MIS (Table E1) (Arndt, Edith 2024; Arndt, Edith and Hester 2025; Arndt, E et al. 2021; Department of Agriculture 2023; Hayes, Inglis and Barry 2019; Schneider, Karen et al. 2020). Since this system is already established and evidence-based, this study strongly supports the notion that SIDS can potentially adapt key elements to their local context by adapting the Australian model to suite a SIDS context. Adopting the existing model would, allow for more efficient implementation and effective risk reduction with limited resources. Adopting Australia's ship biofouling management structure will provide coordination across each component of the system, leading to stronger performance and more effective use of resources. (Bland, L.M. et al. 2024; Outhwaite 2010; Schneider, Karen et al. 2020). This will give SIDS the opportunity to move from fragmented, sectoral responses to a holistic and integrated biosecurity system that will address interconnected challenges they face (Arthur et al. 2008; Bland, L.M. et al. 2024; Heikkilä 2011; Outhwaite 2010).

Table 5.2 Detailed Pre-border, border and post-border ship biofouling management measures implemented in Australia (Department of Agriculture, Fisheries and Forestry (DAFF), 2024).

Pre-Border	<u>Proactive biofouling management option 1:</u>	<u>Proactive biofouling management option 2:</u>	<u>Proactive biofouling management option 3:</u>
(Pre-Arrival Report)	Effective Biofouling Management Plan (BFMP) and Biofouling Record Book (BFRB) meeting the minimum standard set out in the Australian biofouling management requirements. <i>Provide BFMP & BFRB to DAFF.</i>	Vessel has been cleaned of all biofouling within 30 days prior to arrival in Australia’s territory. <i>Provide cleaning report and supporting photographs that meet minimum standard set out in the Australian biofouling management requirements.</i>	Alternative biofouling management method that has been approved by DAFF. Approval of alternative method should be obtained no later than 30 days prior to arrival in Australian territorial seas. <i>Provide most recent in-water inspection and cleaning reports and evidence to support your application.</i>
Border (Vessel Inspection)	Biofouling risk assessed from Pre-Arrival Report responses guide vessel inspection and arrival actions.	Hull inspections are conducted by divers and Remote Operated Vehicles (ROV), with ROV imagery and sonar used to measure biofouling depth. Seized foreign fishing vessels undergo inspection before being hauled out and destroyed.	
Post-Border (MIS Detection)	Early detection of marine invasive species using settlement plates, plankton tows, seawater samples, shoreline surveys, crab traps, sediment grabs, visual inspection, Remote Operated Vehicles (ROV) inspections, and citizen science reporting. eDNA analysis is conducted on biofouling organisms on settlement plates, water samples, and plankton to identify invasive species.		

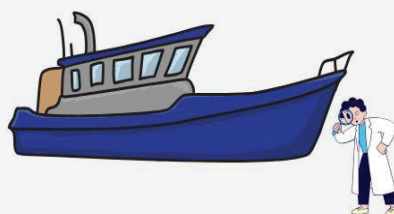
Australian Biofouling Management System



Mandatory Pre-arrival Reporting and demonstration of proactive biofouling management by vessel owners/operators



Verification inspections on arrival to ensure proactive biofouling management reported by vessel owners /operators have been implemented



Surveillance and monitoring programmes at entry points to detect MIS incursions



Figure 5.3 Pre-border, border and post-border measures of the Australian Biofouling Management System.

5.3.2 Resource requirement and running costs

Table 5.3 Summary of the resources, operational costs and implementation challenges associated with managing ship biofouling in Australia, based on surveys, interviews, and Budget Paper No. 3 (2024–2025). The Pest and Disease Preparedness and Response costs apply to the entire biosecurity system, not just biofouling.

Biosecurity Component	Resources required	Costs	Funding type	Implementation challenges
Pre-border	- Human (biosecurity departments staff) - Financial (State contribution) - Organisational Capability (Biosecurity legislations, policies, plans, guidelines, pre-arrival report (PAR) through the Maritime and Aircraft Reporting System (MARS), stakeholder engagement and communication)	Staff salary costs	National	Policy and legislative gaps include poor understanding of legal requirements, unrealistic regulatory expectations, lack of a centrally administered program with adequate staffing, limited national oversight of overseas recreational vessels, insufficient legislative power to enforce biofouling management, and slow progress due to reliance on slow international policy development processes and slow Commonwealth legislation updates.
Border	- Human (biosecurity departments staff, consultants, divers) - Financial (State contribution) - Organisational Capability (Biosecurity legislations, policies, plans, guidelines, stakeholder engagement and communication) - Physical (Remotely Operated Vehicles (ROVs) and underwater cameras)	Staff salary costs (e.g. \$40,000 annual allocation in Victoria; contracted diver inspections at \$4,000–\$7,000/day)	State	Vessel inspections are constrained by staff availability, operational and safety limitations, low visibility, weather, equipment loss, and permitting/security requirements for Defence vessels with financial costs for hiring divers and ROVs adding further limitations. Additional challenges include poor understanding of legal requirements, unrealistic regulatory expectations, lack of a centrally administered program, policy and legislative gaps, and reliance on slow

				international measures to implement national standards.
Post-border	- Human (taxonomists, scientists, biosecurity departments staff, port staff, consultants, divers) - Financial (National, State and Stakeholder contributions) - Organisational Capability (Biosecurity legislations, policies, plans, guidelines, stakeholder engagement and communication, data and information management, partnerships, research and innovation, monitoring and evaluation) - Physical (surveillance equipment such as settlement arrays/plates, sediment grabs, Remotely Operated Vehicles (ROVs), plankton tows, boats, and underwater cameras)	Staff salaries; port surveillance contributions (\$20,000–\$40,000 annually); \$123.5 million for Pest and Disease Preparedness and Response Programs (2024–2025); and up to \$5 million annually for an agreed national biosecurity incident response.	National, State & Stakeholder contributions.	Surveillance and response efforts face multiple challenges, including high costs for staffing, training, and equipment, limited state funding, and inadequate infrastructure such as large vessel slipping facilities. Pest detection is constrained by limited taxonomic expertise and validated assays. Coordination is hindered by technical and operational disconnects, fragmented agency responsibilities during incursions, and reliance on annual DAFF port agreements. Other barriers include low numbers of qualified biofouling inspectors, poor understanding of legal requirements, limited industry involvement, insufficient national oversight (including Naval sites), policy and legislative gaps, reliance on slow international measures, and slow or constrained eDNA surveillance due to technical limitations and high costs. The absence of a centrally administered program with adequate staffing further exacerbates these vulnerabilities.

Table 5.4 *Resource requirements, running costs, and cost-effectiveness ranking of Australian biofouling management strategies for potential adaptation in Small Island Developing States.*

Measures	Biosecurity Component	Resource Requirements	Running Costs	Cost-effectiveness
Pre-arrival biofouling risk assessment	Pre-border	Low	Low	High
Hull inspection	Border	Medium	Medium	Medium
Surveillance/detection, Rapid response to MIS incursion and recovery	Post-border	High	High	Low

The advantage for adapting Australia’s biofouling management system to SIDS was further explored in terms of cost-effectiveness and implementation challenges. This included the resources required, the ongoing operational costs needed and the challenges that need to be addressed to sustain each strategy. The analysis showed that the resource requirements, costs associated, and challenges faced with ship biofouling management vary across the pre-border, border, and post-border components (Table 5.3). Pre-border activities primarily involve staffing and organisational capability, with relatively low direct operational costs. Border activities require added specialist resources, such as contracted divers and inspection technology, resulting in higher day-to-day expenses. Post-border activities, that comprise surveillance, monitoring, incident response and adaptation and recovery, represent the most resource intensive component due to the need for specialised personnel, laboratory capability, equipment, and multi-level funding. This is reflected in higher expenditure at the national level, including broad biosecurity preparedness programs and incident-response commitments.

Challenges at the pre-border stage was observed to be largely organisational, stemming from the absence of internationally binding instruments with standardised biofouling measures. This gap creates uncertainty, inconsistent standards, and reliance on slow, consensus-driven processes, weakening the system’s capacity to manage biofouling risks effectively. Vessel inspection at the border stage represents a distinct operational-level challenge as inspection activities are constrained by human, financial, and physical resource limitations, alongside organisational deficiencies. Collectively, these factors make the operational implementation of border management substantially more complex than pre-border measures. Post-border measures like surveillance and response represent a more complex operational challenge than pre-border or border measures due to the requirement for coordinated deployment of human, technical, and organisational resources across multiple and dispersed locations. Unlike pre-border policy-level constraints or discrete border operations, surveillance entails continuous

monitoring, rapid detection, and timely response across diverse stakeholders and environmental conditions. The integration of technical, logistical, and organisational factors amplifies operational complexity, making effective implementation both resource-intensive and highly sensitive to systemic vulnerabilities in biofouling management.

Given the increasing complexity, resource intensity, and operational challenges associated with border inspections and post-border surveillance and response, pre-border measures emerge as a more cost-effective and feasible strategy, particularly for resource-limited contexts. The pre-border ship biofouling measures provide preventive actions that protect marine ecosystems and livelihoods while requiring relatively low resources, aligning with the three critical management priorities (ecological threats, resource availability, and livelihood implications) for SIDS. This underscores the pre-border component of Australia's biofouling management system as the most feasible measure for resource-limited countries like SIDS (Table 5.4). This provides a practical pathway to strengthen biofouling management and reduce MIS risk without the need to replicate the full-scale, resource intensive Australian system.

5.3.3 Adapting the Australian biofouling management system for SIDS

5.3.3.1 Requirements for establishing a biosecurity system for SIDS

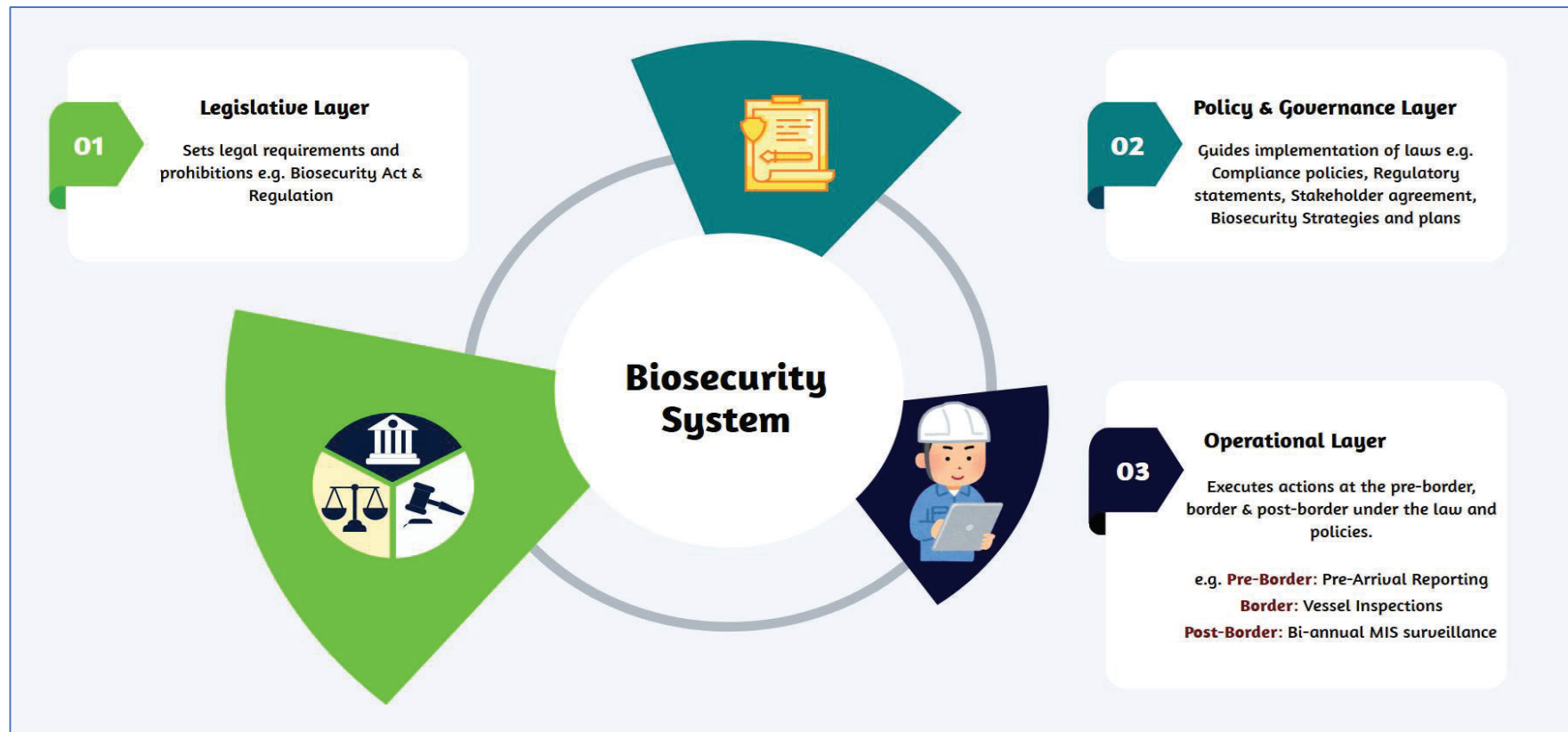


Figure 5.4 Three biosecurity layers: the legislative layer sets out what must be done and what is prohibited, the policy and governance layer defines how the law will be implemented, and the operational layer executes biosecurity actions.

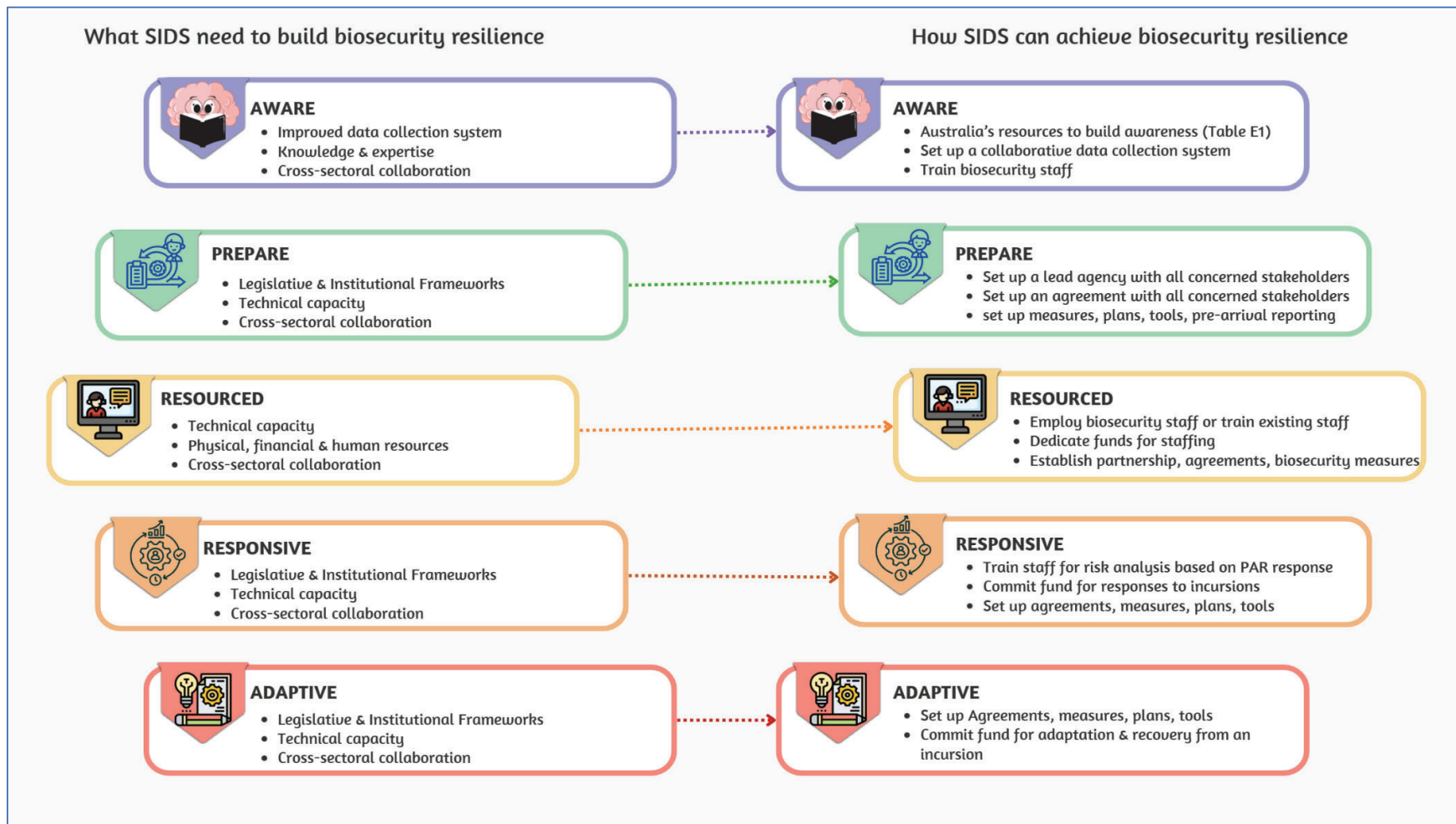


Figure 5.5 Steps for building a resilient biosecurity system for managing ship biofouling in Small Island Developing States, showing the progression from SIDS' needs (left) to the actions and resources required to achieve awareness, preparedness, resourcing, responsiveness, and adaptive improvement (right).

This study shows that the pre-border resource requirements for establishing a biosecurity system in SIDS to control MIS introduction via ship biofouling include human resources (biosecurity department staff), financial support (dedicated funding for staffing, incursion response, and adaptation and recovery), and organisational capability (biosecurity legislation, policies, plans, guidelines, stakeholder agreement, online pre-arrival reporting system, and stakeholder engagement and communication). These resources form the foundation for building a robust biosecurity system, which fundamentally requires integrating three interconnected layers: legislative, policy and governance, and operational layers. Legislative authority provides the legal framework, the policy and governance layer ensure coordinated implementation and oversight, and the operational layer executes pre-border, border, and post-border activities (Figure 5.4). Previous studies support the view that such an integrated structure, underpinned by financial and institutional resources, enhances biosecurity resilience (Anand 2018; Bland, L.M. et al. 2024; Heikkilä 2011; Outhwaite 2010).

5.3.3.2 What does an Australian pre-border system look like in a SIDS context?

Adapting Australia's pre-border biofouling management system to SIDS provides a practical pathway to implement the multiple layers. This work identifies that by tailoring established Australian practices to local capacity; SIDS can build the necessary legislative, governance, and operational frameworks while optimising resource use and focusing on the most feasible measures for their context. The successful establishment of a resilient biosecurity system for SIDS necessitates a systematic process that moves from initial risk identification and engagement to the development of the formal frameworks and operational capabilities. This process aligns with the five dimensions of biosecurity resilience identified by Schneider, Karen et al. (2020): being aware of the risks, prepared to respond, adequately resourced, capable of effective response, and adaptive through learning and improvement. Integrating these dimensions ensures that the biosecurity system is robust, flexible, and able to manage the complex challenges associated with ship biofouling and MIS. Figure 5.5 illustrates this process, showing how SIDS' needs correspond to the steps and resources required to achieve each dimension of resilience.

Step one: Establishing the context, which requires understanding the biological threats and managing the associated risks and uncertainties (Anand 2018; Heikkilä 2011; Schneider, Karen et al. 2020; Waage and Mumford 2008). SIDS can achieve this through collaborative data collection systems and by building the capacity of biosecurity personnel through targeted training. Figure 5.6 and Table E1 support this by outlining key biofouling risks and available management resources. Table E1 compiles guidance materials relevant to biofouling management, including pest risk assessments, pollution risk analyses, legislations and regulations, and operational guidelines. Figure 5.6 illustrates differences in biofouling growth rates between tropical and temperate regions and the fate of biofouling assemblages

during vessel transit, based on data from Floerl, Wilkens and Woods (2010), which informs the proposed biofouling clearance process (Figure 5.7).

Step two: Build capacity for ongoing awareness and regular updates on emerging practices will enable SIDS to adapt to and effectively manage evolving biofouling risks. Given the substantial resource requirements for developing collaborative data collection systems and building the capacity of biosecurity personnel, implementation could be supported through targeted capacity building initiatives such as specialised training workshops for SIDS which could be facilitated by the International Maritime Organization in collaboration with Australia.

Step three: Biosecurity is a shared responsibility and identifying ways of engaging multiple jurisdictions stakeholders is vital for long-term viability and ensures that roles, responsibilities, and contributions across the system are well defined (Anand 2018; Arndt, Edith et al. 2024; Department of Agriculture, Fisheries and Forestry, 2024b; Schneider, Karen et al. 2020).

Australia's National Environmental Biosecurity Response Agreement (Table E1) offers useful guidance for developing such structures. MIS impacts extend beyond national borders to neighbouring countries, which is neighbouring countries should also be included in discussions on MIS management. Because a country's regulations will inevitably influence the wider region, involving neighbouring countries is essential for shaping national policies and ensuring coordinated, effective responses. SIDS should adopt a similar approach by integrating regional partners into consultations on MIS management measures, recognising that invasive species represent a transboundary challenge requiring harmonised regional action. Such engagement can also support partnership building and promote the transfer of resources, expertise, and knowledge across the region.

Ensuring a successful biosecurity system also requires adequate resources, both in capacity and capability, to carry out core activities.

Step four: Determine the resources needed to deliver the system's expected outputs and outcomes (Edith et al. 2024; Schneider, Karen et al. 2020). For SIDS, this includes employing or training biosecurity personnel, securing funding for recruitment where required, establishing partnerships with relevant stakeholders, and ensuring dedicated resources for responding to incursions or disease outbreaks, as well as for adapting to and recovering from such events.

Once the foundational risks, partners, and needs are identified, the structure of the biosecurity system encompassing legislative, policy and governance, and operational layers must be developed and formalised (Figure 5.4). Appropriate legislations, regulations, institutional arrangements and agreements need to be developed to support harmonised strategies and operations. The legislative layer establishes legal requirements, prohibits risks from entering the country, and provides for enforcement and sanctions. The policy and governance layer ensures coordination among stakeholders, while the operational layer carries out direct activities across the biosecurity continuum (pre-border, border, and

post-border) to manage risks (Alawneh et al. 2025; Anand 2018; Bland, L.M. et al. 2024; Edith et al. 2024; Militzer et al. 2023; Schneider, Karen et al. 2020).

These steps are cumulative and iterative, meaning that without the rigour provided by this process, inadequate governance can hinder the successful implementation of border screening and other operational measures (Schneider, Karen et al. 2020). A key challenge for SIDS is the limited legislative and institutional frameworks due to a lack of technical expertise (Chapter 4). Addressing this gap will require targeted support, including specialised training workshops for SIDS which could be facilitated by the International Maritime Organization in collaboration with Australia. In addition, the resources developed by Australia (Table E1) could be adapted to the SIDS context to guide the development of robust legislative and institutional foundations.

Understanding Biofouling Risks: Growth rate and fate from Departure to Arrival

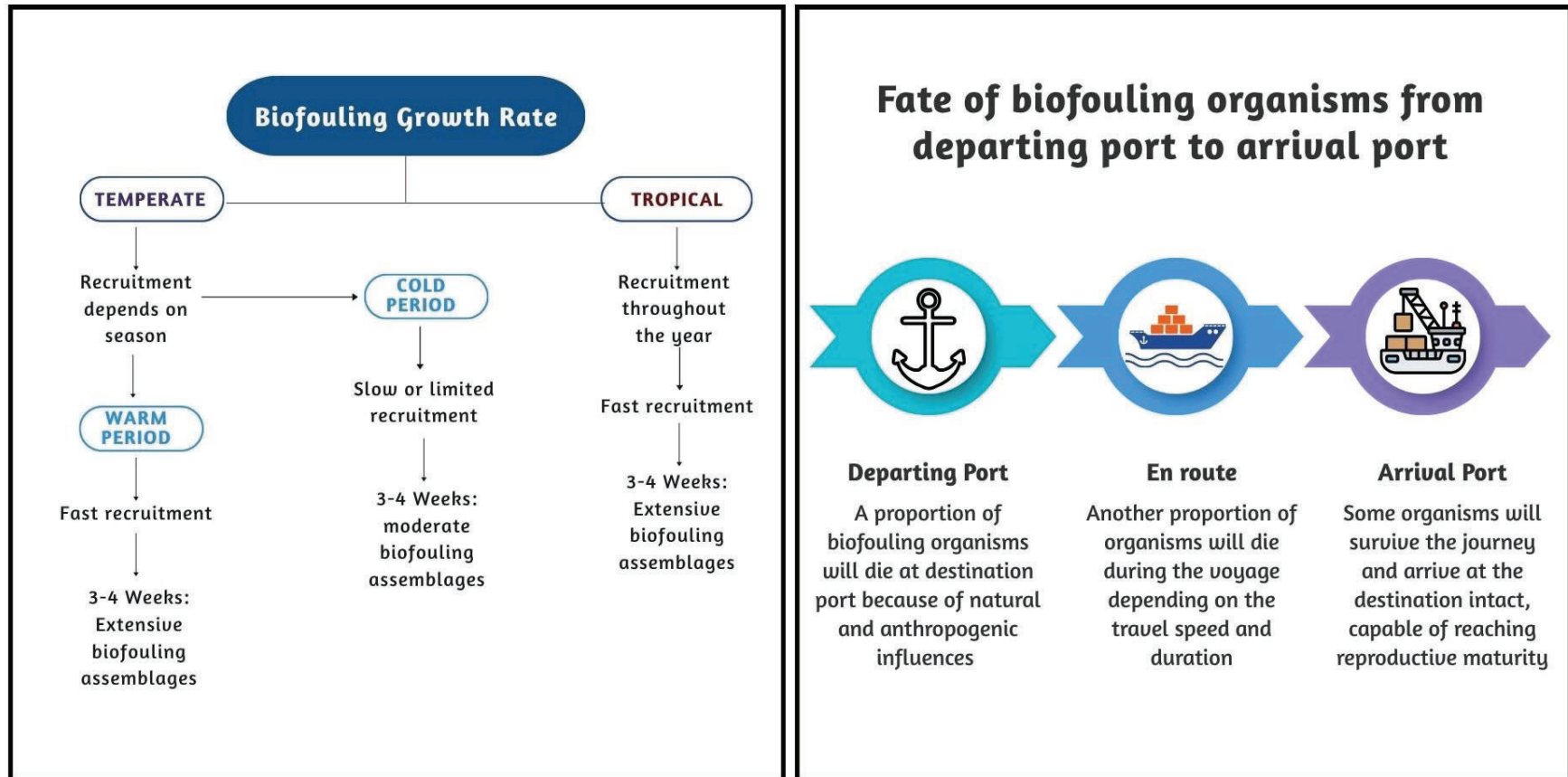


Figure 5.6 Differences in biofouling growth rates between tropical and temperate regions and the fate of assemblages during transit, derived from data presented in (Floerl, Wilkens and Woods 2010).

5.3.3.3 Proposed biosecurity system for managing ship biofouling in SIDS

5.3.3.3.1 *Pre-border component*

In line with Australia's biofouling pre-border management measures, this study recommends a vessel clearance process for SIDS, using Mauritius as an example. The process (Figure 5.7) is based on risk assessment conducted from information provided in the pre-arrival report (PAR). The information required from vessel owners and operators in the PAR can be adapted from Australia's model (Table E1). It is proposed that SIDS also adopt the three recognised biofouling management options currently used in Australia (Table 5.2), and require all vessel types, both commercial and non-commercial, to obtain clearance before entering their territorial waters. In Mauritius, the key stakeholders for ship biofouling management include the Shipping Division of the Ministry of Agro-Industry, Food Security, Blue Economy and Fisheries and the Mauritius Ports Authority (responsible for commercial vessels), the Fisheries Division of the same Ministry (responsible for fishing vessels), and the Ministry of Tourism and Marinas (responsible for recreational boats). The Ministry of Environment, Solid Waste Management and Climate Change is responsible for environmental protection.

Vessels should submit the PAR via an online reporting system, which is routed to the relevant stakeholder based on vessel type. Given the limited resources of SIDS, it is proposed that the PAR be submitted 90 days prior to arrival to allow sufficient time for processing. Risk analysis is expected to take 1–4 weeks, depending on workload and staffing. Unlike Australia, which has multiple ports with initial biosecurity checks, SIDS may have only a single point of entry, or multiple ports with limited resources, necessitating the extended notice and processing periods.

A key principle from Australia is that "Biofouling should be removed in the location where it was acquired before the vessel departs to a new location" (Department of Agriculture, Fisheries and Forestry, 2024a). Using this principle and pest risk assessment studies on biofouling (Figure 5.6, Table E1), separate biofouling risk assessment frameworks were developed for vessels arriving from tropical (Figure 5.8) and temperate (Figure 5.9) regions to guide clearance decisions (Figure 5.7). Following Australian (Microfouling with a fouling rating of FR 20 or less, equivalent to IMO's Rating 1) and IMO (Rating 1) standards, if a vessel's biofouling rating is ≥ 1 prior to departure, the pre-departure rating should be reviewed; a rating of 2 requires an inspection before clearance, and a rating > 2 requires the vessel to be cleaned prior to entering territorial waters. These assessments are supported by submitted evidence, such as photographs or videos, accompanying the PAR. These limitations are intended to minimise the survival of biofouling organisms during transit and protect SIDS' marine ecosystems, as allowing a rating ≥ 2 increases the likelihood that organisms could survive the voyage and pose ecological risks.

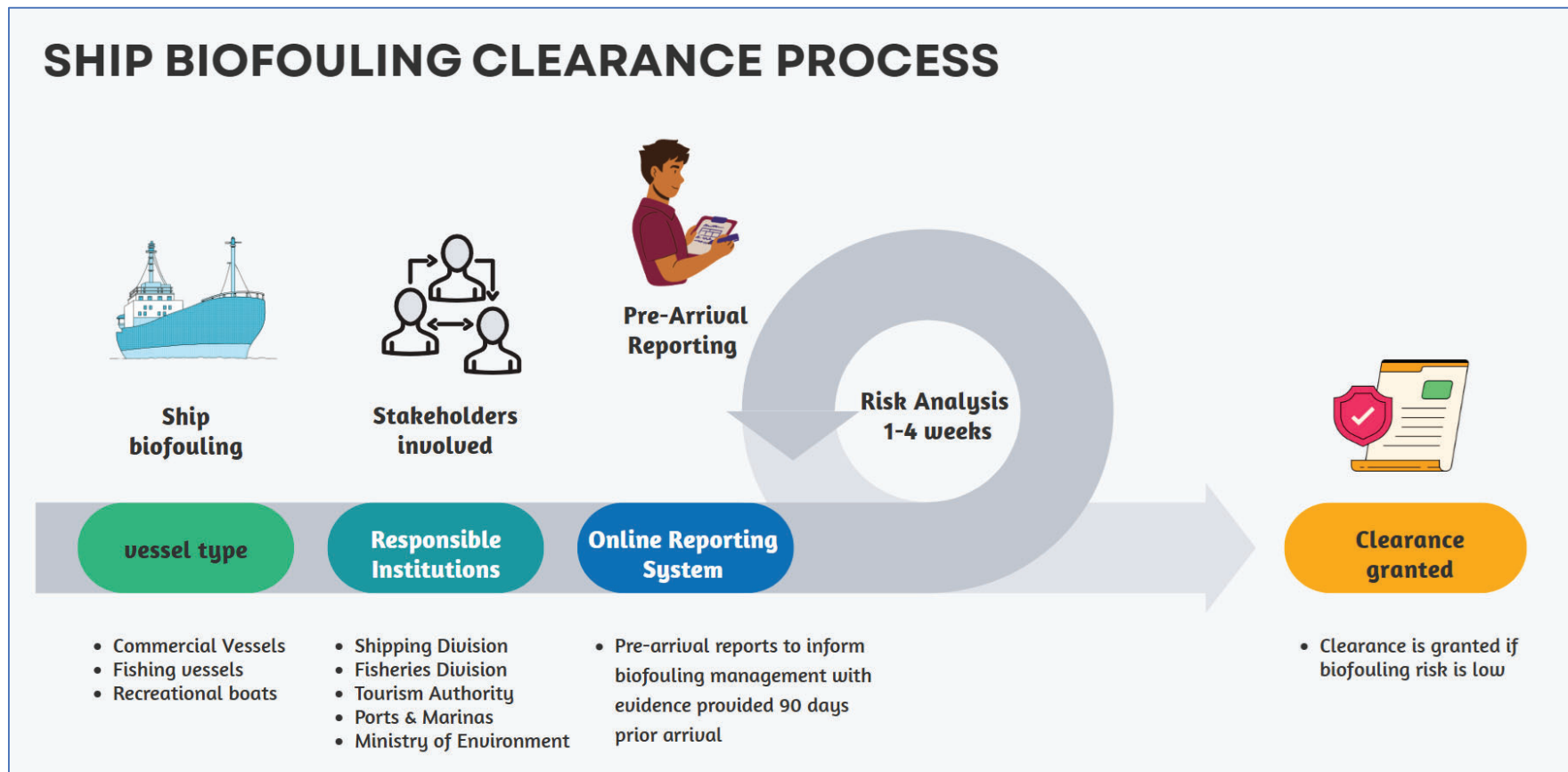


Figure 5.7 Proposed framework for vessel biofouling clearance in SIDS, adapted from Australia’s biofouling management system and illustrated using Mauritius as an example. The figure shows target vessel types, key stakeholders, reporting workflow, and the risk risk analysis timeframe, with separate frameworks for vessels arriving from temperate and tropical regions. Mauritius is used as an illustrative example to show how the framework could be applied in practice. The 90 days pre-arrival reporting and the 1-4 weeks risk analysis timeframes are just suggestions, which can be adjusted based on SIDS capacity and capability.

BIOFOULING RISK ASSESMENT FOR VESSELS ARRIVING FROM TROPICAL PORTS

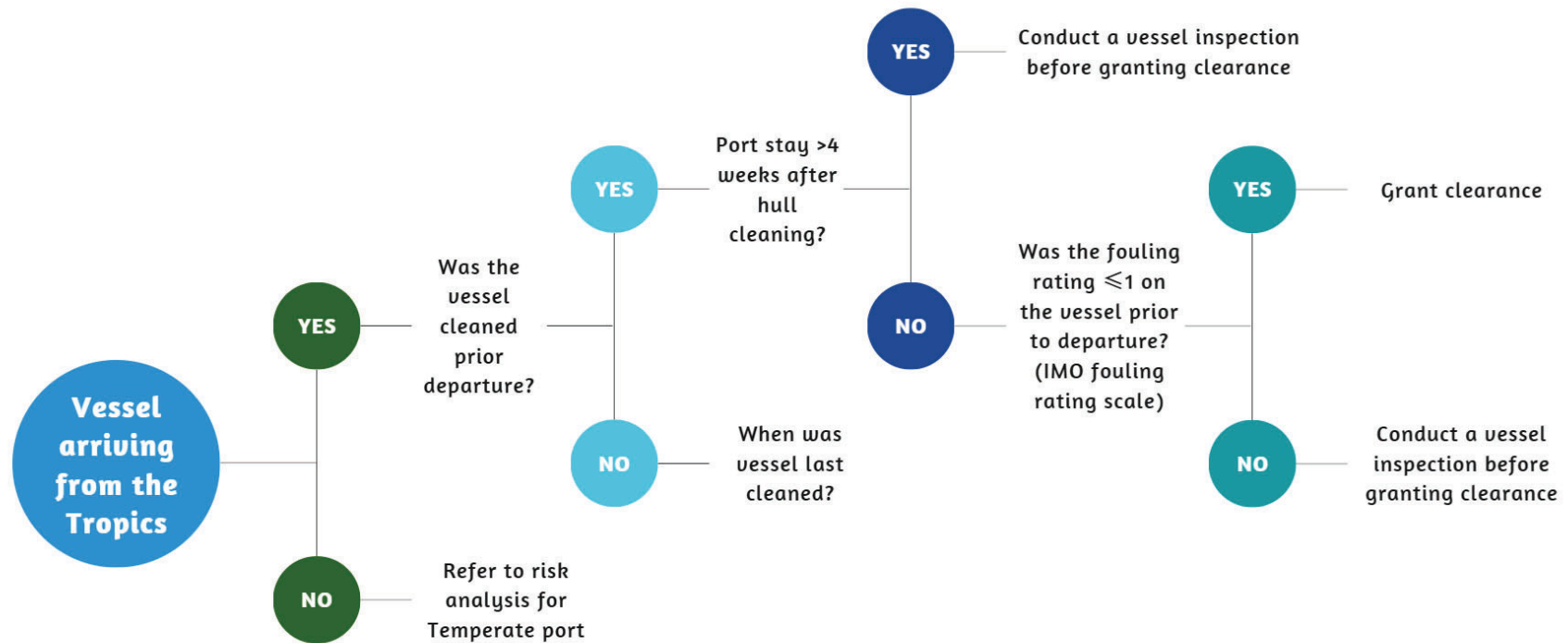


Figure 5.8 Biofouling risk assessment process for vessels arriving from tropical regions, based on biofouling growth rate and fate of biofouling assemblages from the departure port to the arrival port (Figure 5.6), derived from data presented in (Department of Agriculture, Fisheries and Forestry, 2024a; Floerl, Wilkens and Woods 2010; International Maritime Organization 2023).

BIOFOULING RISK ASSESMENT FOR VESSELS ARRIVING FROM TEMPERATE PORTS

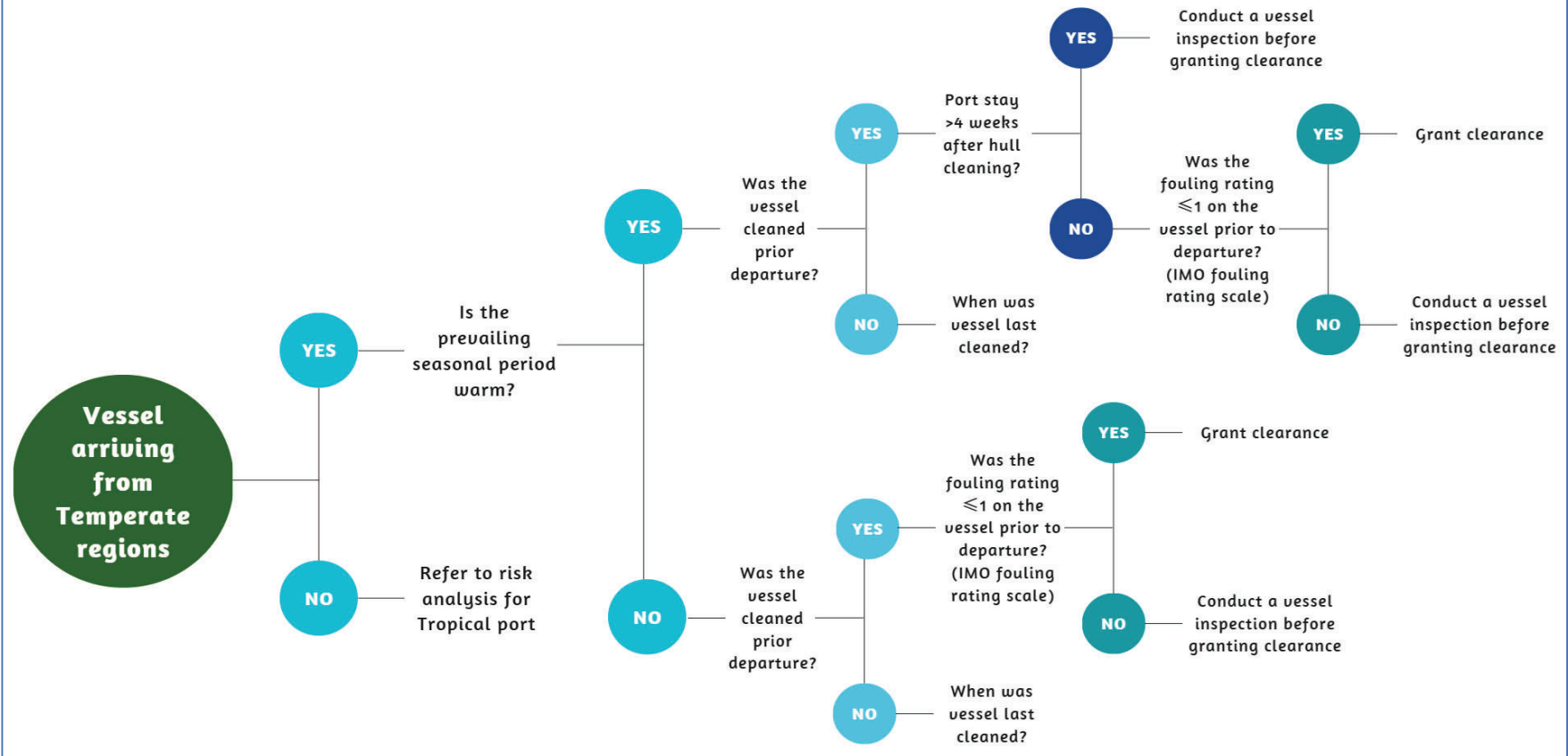


Figure 5.9 Biofouling risk assessment process for vessels arriving from temperate regions, based on biofouling growth rate and fate of biofouling assemblages from the departure port to the arrival port (Figure 5.6), derived from data presented in (Department of Agriculture, Fisheries and Forestry, 2024a; Floerl, Wilkens and Woods 2010; International Maritime Organization 2023).

5.3.3.3.2 *In-water cleaning*

In-water cleaning without waste capture allows 62.3% of biofouling organisms to survive the process, compared to 20.1-37.8% survival in shore-based operations with capture systems (Woods, Floerl and Jones 2012). This shows that in-water cleaning of vessel biofouling presents significant environmental risks even when capture systems are used (Arndt, E et al. 2021; Hayes, Inglis and Barry 2019; Woods, Floerl and Jones 2012), creating substantial biosecurity risks through the release of viable non-indigenous species into marine environments. Management measures should avoid causing greater harm than they prevent, but inaction also carries significant risks, so both considerations must be carefully balanced (Department of Agriculture, Fisheries and Forestry, 2024a).

As an island nation, Australia recognises the risks associated with in-water cleaning. Australia's in-water cleaning guidelines and standards (currently released as an exposure draft) are guided by priorities such as removing biofouling at its source, minimising environmental and chemical risks, supporting operational needs, and reducing biofouling accumulation. They also emphasise balancing the risks of management actions with the risks of inaction and favour out-of-water cleaning where practicable (Agriculture Victoria 2025; Department of Agriculture, Fisheries and Forestry, 2024a; Department of Natural Resources and Environment Tasmania - Biosecurity Tasmania 2024a, 2024b; Government of South Australia 2024; Port Authority of New South Wales 2024). These guidelines align with international conventions and protocols, including the International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFC Convention), the 1996 protocol to the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) and the 2023 Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species (IMO Biofouling Guidelines). These instruments provide guidance on biofouling management plans and record keeping to protect the aquatic environment from invasive species and shipping related contaminants (Department of Agriculture, Fisheries and Forestry, 2024a).

Australia's economic potential has long been rooted in its natural assets, with the Great Barrier Reef alone supporting 77,000 jobs, making it the nation's fifth largest creator of jobs, and contributing \$9 billion to the island's economy in 2023-2024 (Deloitte Access Economics 2025). The Great Barrier Reef already faces pressures such as warming temperatures from climate change, sediment run-off, and crown-of-thorns starfish outbreaks, and emerging biosecurity and contaminant risks associated with in-water cleaning will further intensify these challenges (Deloitte Access Economics 2025). Due to the high biosecurity and chemical contamination risks associated with in-water cleaning, Australia's position is that international vessels should remove biofouling before departure rather than upon arrival. Applications for in-water cleaning in Australia are subject to high scrutiny and are unlikely to be approved because of these risks (Arndt, E et al. 2021). Instead, Australia supports hull grooming, a practice involving habitual, frequent, and gentle underwater removal of slime (microfouling).

Similarly, SIDS demonstrate a comparable awareness of these risks. Relying heavily on the ecosystem services their coral reefs provide such as tourism, fishing, recreational activities, SIDS also endorse a proactive approach. Chapter 4 shows that direct ship biofouling management measures implemented by SIDS primarily focus on hull cleaning, with most countries prohibiting it in territorial and port waters or permitting it only under strict conditions, including the use of capture systems, risk assessments, permits, and reporting. Proactive cleaning presents a reduced risk of releasing viable fouling organisms compared with the reactive removal of more developed fouling communities, including mature calcareous taxa, and also avoids the elevated chemical contaminant loads associated with more intensive cleaning operations (Arndt, E et al. 2021; Hearin et al. 2016; Hearin et al. 2015; Swain et al. 2022). This shared precautionary perspective highlights that proactive biofouling management provides a precautionary, cost-effective management strategy compatible with SIDS' resource limitations and environmental objectives.

Hull grooming enhances vessel efficiency by reducing drag, cutting fuel use, and lowering greenhouse gas emissions (Alghamdi and Quijada 2019; Hearin et al. 2016; Lewis 2020; Swain et al. 2022). When carried out according to coating specifications and local discharge rules, it might not need complete containment of biofouling waste, simplifying logistics and reducing regulatory burdens for SIDS governments (Georgiades, E., Growcott and Kluza 2018). Regular grooming extends coating longevity, minimises the need for high-intensity cleaning, and increases ship availability, while reducing maintenance costs (Hearin et al. 2016; Hearin et al. 2015; Lewis 2020). It also prevents the spread of MIS, supporting biosecurity while placing responsibility with vessel operators. Overall, hull grooming delivers clear economic and environmental benefits through sustainable, proactive biofouling management (Hearin et al. 2015; Hunsucker et al. 2019; Swain et al. 2022).

SIDS often lack the legislative frameworks, resources (human, physical, financial, and organisational), and regulatory authority to manage biofouling risks comprehensively (Chapter 4). Therefore, the safest and most appropriate approach for SIDS is either out-of-water cleaning or in-water hull grooming. Hull grooming provides a precautionary, cost-effective strategy that aligns with their resource capacity and environmental objectives, reducing the risk of introducing MIS without compromising economic opportunities. Extensive studies conducted by Australia have shown that hull grooming is the preferred method for in-water cleaning minimising biosecurity and environmental risks (Arndt, E et al. 2021). However, in the absence of mandatory international standards, if only influential countries like Australia prohibit reactive in-water cleaning, the industry may shift operations to vulnerable, resource-limited countries such as SIDS, where economic pressures may compromise environmental protection. This highlights the urgent need for standardised measures that favour hull grooming to safeguard global marine environments.

5.4 Conclusion

MIS management in SIDS is often spread across multiple ministries, creating confusion, duplication of effort, and fragmented, under-resourced national policies that result in major inconsistencies in implementation and enforcement (Bahamas Environment 1999; Chase et al. 2011; Government of Antigua and Barbuda. Department of Environment 2023a; Mahot 2014; Reaser 2013; Vaas et al. 2017). These challenges are further compounded by limited awareness of MIS, unclear institutional mandates, legislative gaps, financial constraints, and insufficient technical capacity (Chase et al. 2011; Division of Environment and Conservation 2019; Faahi Gahua Takatakaimotu 2024; Kairo et al. 2003; Mahot 2014). As a result, SIDS' preparedness to address MIS introduced via biofouling is widely compromised (Chapter 4). Strengthening legislative and institutional frameworks, building capacity, improving data collection systems, securing sustainable resources, and enhancing coordination, particularly through stronger pre-border measures will help SIDS develop more integrated, cost-effective, and resilient biosecurity systems.

Even in the absence of international binding instruments for managing ship biofouling, Australia's pre-border biofouling measures are well established, evidence based and represent the most resource-efficient component of its biosecurity system. SIDS can adapt these measures without needing to develop a complete system from the scratch. This approach aligns with SIDS' critical management priorities and offers a practical pathway for establishing a resilient biosecurity system without replicating Australia's full-scale resource intensive model. For SIDS with greater capacity, the tools provided in Table E1 offer guidance for building more advanced systems. However, even the pre-border component requires investment, and many SIDS lack the necessary resources. Addressing this challenge will require targeted training and capacity-building initiatives, which could be facilitated by the International Maritime Organization in collaboration with Australia. This study provides practical recommendations for developing and implementing a resilient biosecurity system, including a proposed vessel-clearance process and biofouling risk-assessment guide. It also supports Australia's position that hull grooming is the most appropriate in-water cleaning method when out-of-water cleaning is not feasible, as it poses lower biosecurity and environmental risks while delivering economic benefits through proactive management. Finally, the study highlights the need for international standards that allow only hull grooming as an in-water cleaning practice, ensuring equity, protecting SIDS' marine environments, and preventing inconsistent practices that could undermine their biosecurity systems.

While Australia's framework offers a model for resource-efficient, pre-border measures adaptable to SIDS, its implementation is challenged by structural and resource disparities. Chapter 6 addresses these equity issues by comparing the readiness of Mauritius, as a representative SIDS, with Australia, highlighting gaps that constrain resource-limited countries and exploring ways to promote fairness in international policy development.

6.1 Synthesis of key findings

In this thesis, I identified the complex and multi-level challenges faced by small island developing states (SIDS) in managing the marine invasive species (MIS) issue. These include systemic deficiencies in preparedness and capacity for ship biofouling management, critical governance and regulatory gaps, and the inadequacy of existing international measures in safeguarding resource-limited countries like SIDS. I used a systems-based approach that accounts for the interconnected ecological, social, and governance dimensions of MIS management to address these interlinked challenges. In addition, my analysis developed context-appropriate, cost-effective strategies and recommendations to enhance the capacity and capability of SIDS for managing ship biofouling and addressing the MIS issue in general.

This thesis addressed the critical issues and complexities SIDS face in managing MIS (Chapters 1-6) by identifying the significant importance of interlinked internal and external factors that influence MIS management. More specifically, I: 1) identified and evaluated international policy instruments and their coverage of MIS categories and introduction pathways, and addressed the challenge of inconsistent terminology and regulatory gaps (Chapter 2); 2) evaluated the adequacy of these international policy instruments against SIDS' critical management priorities (ecological threats, resource availability, and livelihood implications) (Chapter 3); 3) assessed the preparedness of SIDS to manage MIS introductions via ship biofouling, as well as the challenges and needs faced in implementing these measures (Chapter 4); 4) evaluated Australia's ship biofouling management framework to identify approaches adaptable to SIDS' unique challenges and needs (Chapter 5) and 5) highlighted structural gaps that constrain resource-limited countries like SIDS, promoting equity and fairness in global marine biosecurity governance (Chapter 6).

Overall, my research has three key findings:

1. Challenges associated with MIS management are mostly due to significant regulatory gaps in international environmental frameworks. Current international policy instruments are failing to address resource vulnerability, contributing to persistent governance gaps in SIDS. This issue is exacerbated by the reliance on voluntary measures due to the lack of binding measures and the lengthy, costly process of developing binding instruments. However, I also found that leveraging existing international policy instruments to address MIS is both feasible and has the potential to significantly enhance global biosecurity.
2. Small island developing states are not sufficiently aware, prepared, resourced, responsive, or adaptive to manage ship biofouling and MIS effectively. They require substantial and immediate resources to protect themselves against the MIS issue. The utility of Australia's

pre-border biofouling approach as a model for use in SIDS, provides a practical model that they can adapt to address their capacity and capability limitations without needing to build a complete system from scratch.

3. There is a disparity in regional collaboration among SIDS, which is likely to be a contributing factor to their lack of readiness to protect themselves. Consequently, a restructuring of SIDS regional groupings would promote stronger regional collaboration, shared responsibility, and standardised strategies. Ultimately, stronger mandatory and precautionary international environmental laws are required to strengthen legal and policy frameworks and improve global efforts to manage MIS.

The following section examines each of these findings in detail, analysing their implications for international environmental governance, SIDS capacity and capability, regional cooperation, and the future development of mandatory environmental international instruments.

6.2 Addressing the regulatory gaps in international environmental governance

6.2.1 *Lack of regulations and inconsistent terminology*

The study conducted by Soto et al. (2024) showed that there are currently 59 terms in use to describe or classify non-indigenous species. Building on this, I found that existing international policy instruments similarly employ varied and inconsistent terminologies. This is likely because few binding measures specifically address the introduction of MIS, while most instruments prioritise trade or broader environmental objectives. This further contributes to the inconsistent terminology pool, promotes confusion among decision-makers and in turn hinders effective MIS management (Colautti and MacIsaac 2004; Essl et al. 2018; Soto et al. 2024).

My work also showed that Trade and Aquaculture, two of the three major critical MIS introduction pathways, are mostly regulated by strict rules under binding instruments such as the WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) 1995, while shipping is not fully regulated. Although ballast water and sediments are regulated under the Ballast Water Management Convention (2004), ship biofouling remains subject only to non-binding regulatory measures (GEF-UNDP-IMO GloBallast Partnerships Programme 2017; International Maritime Organization 2025b). Even though the International Maritime Organization announced in April 2025 that it will start the development of a convention to address ship biofouling, the process of developing and establishing international binding instruments are lengthy and costly (Figure 2.1) (GEF-UNDP-

IMO GloFouling Partnerships 2025). In the interim, vulnerable countries such as SIDS that lack awareness and resources remains unprotected against the introduction of MIS and its impacts on the marine resources that sustain their populations.

To address both the issue of terminology inconsistency and lack of binding measures, I evaluated the potential of leveraging existing international policy instruments as a time and resource efficient alternative to developing new MIS-specific conventions from scratch. I consolidated MIS into five analytical categories: All Marine Invasive Species, Biological Structures, Pathogens, Animals, and Plants, to ensure consistency in terminology across international policies and support inclusive management strategies adaptable for SIDS with limited taxonomic precision. Similarly, I categorised pathways according to their functional focus: Shipping, Trade, Travel & Transportation, Release, Aquaculture, Land-based Activities, and No Specific Pathway (where no pathway was explicitly identified) in international policy instruments. I found that most instruments are broadly relevant across the three critical pathways of MIS introduction (Trade, Shipping, and Aquaculture) and address multiple overlapping MIS categories, enabling flexible responses that can strengthen global efforts against MIS. To maximise protection and resource efficiency, I also propose an actionable guidance that strategically match existing international instruments to specific MIS categories and pathways (Chapter 2). This integrated categorisation approach is therefore critical for transforming fragmented international policy instruments into a coordinated and resource-efficient global response to MIS.

6.2.2 *Failure to address resource vulnerability*

My findings highlight how SIDS need cost effective pre-border biosecurity measures to anticipate risks and prevent harmful MIS introductions. The discussion on pre-border measures (see Chapter 5) signal a way forward for SIDS as their implementation require significantly less financial and institutional resources than border and post-border measures as they aim to prevent the introduction of risk material such as MIS before it occurs. Pre-border measures, however, rely heavily on international policy instruments (Bland, L.M. et al. 2024; Schneider, K. and Arndt. 2020). These international environmental regimes do not adopt the precautionary approach that prevents the overall biosecurity risks of invasive species and diseases but are economically biased as they are structurally premised on high levels of scientific, technical, and financial capacity, which many states do not possess (Chapters 3 and 4, (Vennis et al. 2022). I also highlighted that participation was lower in international instruments directly relevant to MIS management when those instruments required substantial technical, financial, or institutional resources, a pattern that highlights the structural inequities limiting global biosecurity support for resource constrained countries like SIDS (Chapter 3).

Even where environmental harm is suspected, responsibility can only be triggered upon the establishment of a strict causal link, a requirement that is exceptionally difficult to satisfy in the MIS

context due to delayed ecological effects, multiple introduction pathways, and the scientific uncertainty inherent in marine ecosystems (Chew and Hamilton 2011; Essl et al. 2018; Mäliksoo 2011; Piria et al. 2021; Seebens et al. 2018; Soto et al. 2024; Tarkan et al. 2024). This resource intensive evidentiary model is institutionalised in the Ballast Water Management Convention (2004). Under Article 8, enforcement is primarily vested in the flag state (Administration) of the vessel, while coastal and port States must either initiate proceedings using their own domestic resources or transmit evidence to the flag state for action. The regime provides no centralised judicial mechanism at the international level, with compliance oversight limited to reporting obligations. As a result, effective enforcement is contingent not only on scientific proof, but also on the availability of institutional, financial, and technical capacity at both the coastal and flag state levels. This structure disproportionately disadvantages resource constrained states like SIDS, which face the highest exposure to MIS risks yet possess the least capacity to meet the Convention's demanding evidentiary and enforcement requirements (Chapters 3 and 4). My findings also showed that existing instruments are insufficient to safeguard SIDS from MIS invasions, primarily because they fail to address resource vulnerability. Most instruments demand substantial financial, technical, and human resources, creating significant implementation barriers for SIDS. Consequently, the effectiveness of international MIS control is fundamentally constrained by a systemic resource availability failure embedded within the design of existing international measures (Chapters 3 and 4).

At the same time, international maritime regulation, particularly under instruments developed by the International Maritime Organization, places strong emphasis on preventing the undue detention or delay of ships and guarantees compensation to vessels that are wrongfully delayed. This creates a regulatory contradiction. On the one hand, states are expected to prevent environmental harm through inspection, risk assessment, and control measures. On the other hand, they face legal and financial consequences if such measures are later deemed excessive or unjustified. This tension significantly discourages robust precautionary action, particularly in the case of MIS, where scientific uncertainty is high and proof is difficult to establish. These structural constraints raise a fundamental question as to how states, especially SIDS, can meaningfully protect themselves or conduct thorough risk assessments without the persistent risk of financial liability for ship delays.

Supporting evidence from earlier scientific studies and documented cases have confirmed that MIS pose real and significant threats to marine biodiversity, fisheries, and coastal economies (Costello et al. 2025; Department of Environmental Conservation 2024; World Shipping Council 2021). The transboundary nature of MIS highlights how MIS can spread across regions, impacting multiple states and shared marine ecosystems (Katsanevakis et al. 2023). Given the proven high socio-economic and ecological stakes, complex marine dynamics, and the inherent uncertainties in predicting species behaviour, the management of MIS must be grounded in the precautionary principle (Essl et al. 2018; Katsanevakis et al. 2014; Seebens et al. 2018). Environmental international instruments should prioritise preventive

action, relying on precaution in the face of scientific uncertainty and the potential for serious harm rather than demanding exhaustive proof (Bland, L.M. et al. 2024). Additionally, the polluter pays principle, as recognised in the *Rio Declaration on Environment and Development (1992)*, Principle 16, must be enforced. In this context, measures addressing ship biofouling should ensure that vessel owners and operators clean their hulls prior to departure to reduce the risk of introducing MIS, lower additional fuel costs, decrease greenhouse gas emissions, and ensure that the costs of prevention are borne by the responsible parties rather than by affected countries. Regarding in-water cleaning, only hull grooming, which carries lower risks, should be permitted (Chapter 5).

Anchoring policy in precaution, supported by scientific evidence from existing literature, accountability mechanisms, and equity considerations, ensures a balanced and equitable approach that safeguards vulnerable marine ecosystems while remaining consistent with international trade and environmental obligations. This principle requires mandatory actions that shift the governance burden upstream to the sources of risk, aligning with both the precautionary and polluter pays principles. This means future binding instruments, like the upcoming IMO convention on ship biofouling, must mandate vessel owners to clean hulls prior to departure to minimise MIS transfer. Furthermore, equity considerations translate into international standards enforcing controlled in-water hull grooming measures as the preferred in-water cleaning method. These actions empower SIDS by promoting resource-efficient, pre-border biosecurity without the need for resource-intensive, post-incursion responses.

6.2.3 Voluntary measures and slow processes for binding instruments

My research (Chapters 1-5) along with various studies, has shown that an over-reliance on voluntary measures, combined with the lengthy and costly process of developing binding instruments, contributes to ongoing governance weaknesses. While voluntary guides can offer valuable technical and scientific guidance, they are often disregarded as they lack mandatory obligations and enforcement mechanisms. Mandatory measures on the other hand provide enforceable authority and accountability, giving legal weight to obligations. According to Bland, Lucie M. et al. (2024), international binding measures provide the foundation and first line of defence against invasive species and diseases by helping to prevent introductions of biosecurity risks.

However, as noted by Vennis et al. (2022), the designation of an instrument as “legally binding” does not necessarily guarantee its effectiveness, a point I further illustrate in Chapter 3, where many mandatory instruments remained unenforceable because the demanding implementation requirements exceeded available resources. Furthermore, international environmental instruments predominantly operate as soft law, offering guidance rather than enforceable obligations and must be implemented domestically through national legislation and action. Their success therefore depends on domestic

priorities and capacities, and is often undermined by varying local contexts and competing social or economic interests (de Sadeleer 2024; Hanf 2019).

Developing binding environmental instruments that do not embed a precautionary approach to account for ecological threats, resource availability, livelihood implications and accountability risks create barriers for resource-limited countries like SIDS instead of providing security. This is especially problematic for threats like MIS introduced via ship biofouling where existing measures are voluntary. To be effective, international environmental instruments must adopt precautionary approaches, include clear and enforceable obligations (including polluter pays principles), support national capacity-building, and protect resources. However, given how costly and lengthy it can be to develop binding measures, SIDS remain vulnerable in the interim. For that reason, I propose practical system components such as vessel-clearance processes and risk-assessment guides (Chapter 5) to help manage biofouling risks even in the absence of fully developed binding instruments.

6.3 Making SIDS sufficiently aware, prepared, resourced, responsive, or adaptive

The outcome of this research reveals that SIDS lack resilient biosecurity systems compared to developed countries, as they face complex and interlinked challenges that arise both internally, at the national level, and externally, through global pressures. According to Schneider, Karen et al. (2020) a resilient biosecurity system needs to be aware, prepared, resourced, responsive, and adaptive. Understanding the biosecurity risks and knowing how to address them with the necessary resources is what makes a biosecurity system successful. Accordingly, I used a stepwise approach to examine these interconnected factors and to inform SIDS' preparedness and biosecurity capacity to manage MIS. I used evidence from national measures and stakeholder experiences and perceptions as foundational data for the development of targeted strategies to address regulatory gaps and strengthen marine biosecurity in SIDS (Chapters 4 and 5).

First, in Chapters 2 and 3, I highlighted external challenges including regulatory gaps in international environmental governance such as lack of regulations and inconsistent terminology, policy instrument failure in addressing resource vulnerability, limitations of voluntary measures and slow processes for binding instruments and the lack of strong enforceable obligations. Then in Chapter 4, I identified internal challenges such as focus on terrestrial invasives, lack of legislative and institutional frameworks, lack of knowledge and expertise, lack of financial resources, lack of equipment and technology, data scarcity, limited workforce, lack of political commitment and enforcement, multisectoral and unmanaged points of entry as well as additional external challenges such as delayed visibility of impacts, jurisdictional dependency, language barrier, climate change, no standardised

mandatory measures. Through these steps I identified key challenges and needs and provided targeted solutions (Chapters 2 and 5).

My analysis of the challenges and needs of SIDS highlighted that pre-border measures are the most effective approach for resource-limited SIDS to prevent the introduction of MIS. Leveraging Australia's extensive knowledge and resources can help reinforce SIDS' capacity to manage these risks. Together, these measures strengthen preparedness, enhance biosecurity systems, and reduce the likelihood of invasive species introductions, including those associated with ship biofouling, thereby contributing to a more resilient framework for protecting marine ecosystems. While these measures strengthen preparedness and early intervention, I have shown that SIDS will still require regional and international support to address the resourcing, responsiveness, and adaptive dimensions of a fully resilient biosecurity system (Chapters 3, 4 and 5).

In Chapter 3, I demonstrated that SIDS show relatively high participation in broad, longstanding maritime and environmental instruments that generally require fewer resources to implement. In Chapter 4, I further showed a predominance of indirect measures, such as the International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS Convention) and the use of marine notices for unofficial biofouling record books, in the approaches adopted by SIDS to address ship biofouling. My data showed that Pacific and Caribbean SIDS had higher reliance on indirect measures compared to AIS SIDS. Overall, the integration of marine biosecurity remains limited in the Pacific and AIS, whereas most Caribbean SIDS have implemented a limited number of direct, species-specific measures targeting a few well-known MIS, including lionfish (*Pterois volitans*), Halophila seagrasses (*Halophila spp.*), sun corals (*Tubastraea spp.*), and the Asian green mussel (*Perna viridis*). Overall, these patterns reflect the limited institutional capacity and low policy prioritisation of marine biosecurity across SIDS, which constrain the development of proactive and coordinated frameworks.

Although marine biosecurity preparedness remains limited across all SIDS, the comparatively stronger capacity observed in Caribbean SIDS may be attributed to advantages including geographic proximity to major global markets, early development of international tourism and offshore banking, and more extensive colonial infrastructure development (Mcelroy and Medek 2012). In Chapter 4, I showed that Caribbean SIDS have integrated marine biosecurity with species-specific strategies in response to consequential damages caused by the introduction and rapid spread of MIS. A predominant example is the invasion of the lionfish (*Pterois volitans*) across the region, which caused declines in commercial fisheries and impacts on tourism (McGuire and Hill 2021). Due to their geographical proximity, these states were able to act collectively and develop coordinated reactive strategies at both the national and regional levels (Hixon et al. 2016; Morris 2012). Similarly, I observed a comparatively higher capacity among Pacific SIDS, which may be linked to their participation in pooling initiatives, where countries collaborate regionally to share resources, expertise, and capacity, facilitating compliance and

coordinated action (Dornan and Newton Cain 2013). In contrast, I found that AIS SIDS displayed comparatively weaker capacity, likely associated with greater geographic dispersion and fewer opportunities for regional cooperation than those available to Pacific and Caribbean SIDS. These regional disparities in resource distribution and external support (Dornan and Newton Cain 2013; Mcelroy and Medek 2012), shape the ability of SIDS to engage with and implement international commitments. This uneven capacity landscape underscores the need to restructure current SIDS regional groupings to promote stronger regional collaboration, shared responsibility, and more standardised marine biosecurity strategies.

6.4 Equity and fairness in global marine biosecurity governance

The outcome of this research reveals that levels of national capacity and capability differ significantly between developed and developing countries like SIDS. Developed countries like Australia are well resourced to implement advanced and resilient biosecurity systems whereas most SIDS which do not even have a biosecurity system in place (Chapters 4 and 5). A comparison between Australia and Mauritius clearly illustrates this disparity. Given the transboundary nature of MIS, it should be treated as an issue that needs to be addressed at the global level and not solely at the national level. Effectively addressing this issue requires a resilient biosecurity system supported by adequate national capability and capacity including financial, human and physical resources, and organisational capabilities (Bland, L.M. et al. 2024; Schneider, Karen et al. 2020).

My comparative analysis showed that Australia is well prepared as it demonstrates high awareness of ship biofouling, has well developed plans, tools and agreements in place and possess the financial, physical and human resources as well as the organisational capability needed to address ship biofouling and MIS introductions. In contrast, Mauritius is aware of the issue but only has limited management measures (only in-water cleaning measures in place) and lacks the resources, responsiveness, and adaptability required for an effective biosecurity system. My analysis also indicated that even SIDS that are overseas territories of developed and well-resourced sovereign states face considerable challenges, as limited administrative autonomy and restricted decision-making authority hinder their ability to implement timely and context-specific biosecurity measures. More broadly, what is clear from my data is that the overall preparedness of SIDS to address ship biofouling remains low (Figure 6.1 and Table 6.1). This appears to result from multiple, interlinked challenges that constrain national capacity and capability, making it difficult for SIDS to develop even a basic biosecurity system (Chapters 4 and 5).

Nonetheless, in the absence of standardised international policy instruments, even developed countries such as Australia face distinct challenges. My data showed that Australia's primary challenges relate

to maintaining and effectively implementing its established biosecurity system. Although mandatory biofouling management measures are in place, legal and governance challenges persist, including insufficient legislative authority, poor understanding of requirements, and inconsistent regulatory expectations. Resource and organisational capacity constraints also remain, such as limited staff availability, the high financial cost of hiring divers and remotely operated vehicles (ROVs), limited national oversight of overseas recreational vessels, and slow updates to Commonwealth legislation. However, my research showed that in comparison with SIDS, which often lack a biosecurity system altogether or operate fragmented systems, Australia remains substantially better prepared. Notably, approximately 50% of SIDS are not even aware of the ship biofouling issue and will therefore require extensive support to address the full suite of challenges they face. Initial priorities must include building awareness and securing the necessary resources to develop national plans, tools, and agreements, alongside sustainable funding for staffing, training, and essential equipment.

My work shows that equity and fairness are currently lacking in global marine biosecurity governance. While developed countries such as Australia possess the financial, technical, and institutional capacity to implement advanced biosecurity measures, most SIDS have little basic awareness of the ship biofouling issue, let alone the ability to implement comprehensive management systems. SIDS remain burdened by persistent internal and external pressures, including limited financial resources, human capacity constraints, and competing national priorities, which further widen the implementation gap. Addressing this disparity requires a shift from voluntary and fragmented approaches toward stronger, mandatory international environmental instruments that adopt a precautionary, source-control approach to ship biofouling. Such an approach would ensure that the burden of marine biosecurity is not unfairly placed on the least-resourced nations while the sources of risk remain largely unregulated. My research also highlights that equity and fairness in marine biosecurity governance can only be meaningfully achieved through coordinated and enforceable global actions that empower SIDS and other resource-limited countries through sustained international financing, technical assistance, and capacity building mechanisms.



Figure 6.1 Preparedness (capacity and capability) of Australia, Mauritius and SIDS in general for addressing ship biofouling and MIS.

Table 6.1 *Challenges that Small Island Developing States and Australia face in managing ship biofouling and marine invasive species.*

MAIN CHALLENGES/ BARRIERS	SIDS	Australia
Climate Change & Environmental Factors	Management challenges due to climate change,	Vessel inspections are constrained low visibility and weather, warmer temperatures due to climate change will lead to greater ranges for pest species.
Lack of Financial Resources	Anti-fouling paint expensive, lack of funding, no quantification of resources allocated,	Vessel inspections are constrained by financial costs for hiring divers and ROVs adding further limitations. Surveillance and response efforts face multiple challenges, including high costs for staffing, training, and equipment, limited state funding, Slow or constrained eDNA surveillance due to technical limitations and high costs. No funding certainty at the State level for surveillance to continue.
Lack of Human Resources (Lack of Knowledge and Expertise, Limited Workforce)	Lack of knowledge, lack of expertise, low awareness of hull fouling as a vector and threat, terminology used not understood by layman, manpower, human resources	Vessel inspections are constrained by staff availability and permitting/security requirements for Defence vessels. Pest detection is constrained by limited taxonomic expertise and validated assays. Low numbers of qualified biofouling inspectors. Slow or constrained eDNA surveillance due to technical limitations and high costs.
Lack of Organisational capability (Lack of Legislative and Institutional	No formal legislation, legislative and bureaucratic delays, insufficient integration of environmental-	Policy and legislative gaps include poor understanding of legal requirements, unrealistic regulatory expectations,

Frameworks, Lack of Technology, Data & information, multisectoral, Lack of Political Commitment and Enforcement)	economic linkages in national policy frameworks, lack of technology and software, no data, limited data, no robust biodiversity baseline information, data not available or shared with other institutions, limited risk assessment, involves different stakeholders with different mandates, low political priority, limited or no implementation of action, weak control or enforcement mechanisms	lack of a centrally administered program with adequate staffing, limited national oversight of overseas recreational vessels, insufficient legislative power to enforce biofouling management, and slow progress due to reliance on slow international policy development processes and slow Commonwealth legislation updates. Vessel inspections are constrained by permitting/security requirements for Defence vessels. Coordination is hindered by technical and operational disconnects, fragmented agency responsibilities during incursions, and reliance on annual DAFF port agreements. Limited industry involvement, insufficient national oversight (including Naval sites),
Damage not visible straight away	The ecological and economic damage caused by marine invasive species can take weeks, months, or even years to become apparent, making early detection and prevention especially challenging.	-
Focus on Terrestrial Invasives	Management measures are more focused on terrestrial invasive species	-
Jurisdictional Dependency	Overseas territories must depend on the legal authority of the sovereign state	-
No Standardised Mandatory Measures	No consistent, uniform rules applied everywhere	Policy and legislative gaps due to reliance on slow international policy development processes

Unmanaged points of entry	Ports or coastal access areas that lack official monitoring, security, or administrative control, allowing entry without systematic checks	-
Language Barrier	Difficulty in communicating with local communities, stakeholders, or authorities in the region where the ship is arriving, due to differences in language between those regional actors and the ship crew, inspectors, or external agencies	-
Work Health and Safety	-	Vessel inspections are constrained by operational and safety limitations.
Lack of Physical resources	Lack of equipment, docking facilities	Vessel inspections are constrained by equipment loss. Inadequate infrastructure such as large vessel slipping facilities.

6.5 Challenges and directions for future research

Marine invasive species introduction is a complex issue that requires urgent action. Most information on international policies addressing MIS comes from grey literature (Chapter 2), with few publications in peer-reviewed journals, highlighting a lack of research in this field. In my view, limited researcher involvement in evaluating and challenging the development and implementation of international policy instruments contributes to their ineffectiveness. Establishing a convention without revising it to reflect evolving environmental challenges risks rendering these instruments obsolete. Similarly, conducting scientific research without ensuring its translation into policy and practice can be as detrimental as inaction itself. Supporting this perspective, the study *Out of the Loop: Why Research Rarely Reaches Policy Makers and the Public and What Can Be Done* found that although researchers publish in peer-reviewed journals, only 15% (40 out of 268 scientists surveyed) believe these publications lead to real-world conservation outcomes, illustrating how limited engagement in translating research into policy undermines the impact of scientific knowledge. A strong focus on academic recognition over practical solutions reinforces the persistent gap between scientists and policymakers, while conflicting priorities, different ways of working, and misaligned institutions further weaken the credibility and effectiveness of environmental governance (Gholami et al. 2016; Koetz, Farrell and Bridgewater 2011; M. Agung Akbar 2024; Shanley and López 2009). Overall, the current approach to MIS policy development is fundamentally compromised by this systemic disconnect, and without active researcher engagement and adaptive policy frameworks, international environmental instruments risk becoming ineffective.

To bridge the gap between science and policy, research should prioritise translating scientific findings into practical policy recommendations and management actions. This can be achieved by encouraging collaborative research partnerships between scientists, policymakers, and local stakeholders, building capacity for both scientists and policymakers to improve communication, interpretation, and application of scientific evidence, and establishing regular review mechanisms to update international instruments in line with evolving environmental challenges.

Likewise, designing targeted strategies to address regulatory gaps and enhance marine biosecurity requires insights from national measures and stakeholder perspectives. However, several challenges were encountered during data collection, which may have affected the depth and breadth of the findings (Chapters 4 and 5). For SIDS, although surveys were distributed in all official languages, follow-up communication, particularly during phone interviews, was limited to English and French. This restricted engagement with respondents from non-Anglophone and non-Francophone countries, potentially affecting the richness of qualitative insights. Coordinating interviews and surveys across the diverse time zones of the SIDS also presented scheduling difficulties, often resulting in missed or rescheduled engagements. Additionally, many government websites lacked accessible, up-to-date, or comprehensive information, highlighting issues of transparency and digital access. Another related

challenge was the lack of accessible information on the ratification status of overseas territories. Not all sovereign states provide clear guidance on whether the ratification of a convention automatically extends to their territories, making it difficult to determine the legal applicability of international instruments and limiting the ability to assess compliance and the effectiveness of biosecurity measures at the territorial level. Due to limited funding, in-person visits to all 57 SIDS were not feasible, so data collection relied heavily on remote methods, which can limit relationship building and access to nuanced, context-specific insights. In contrast, challenges in Australia were primarily linked to low participation from industry and marinas, reflecting a lack of interest and underscoring the need for greater stakeholder awareness and engagement to support effective biosecurity measures. Therefore, my findings should be supplemented by further in-depth studies across all SIDS, led by international organisations such as the United Nations Environment Programme (UNEP) or the International Maritime Organization (IMO) and conducted by local researchers. Similar studies in Australia could focus on increasing stakeholder participation, particularly from industry and marinas, to improve engagement and support for biosecurity measures. Such studies would provide context-specific insights to inform the design of tailored strategies that support the development and strengthening of biosecurity systems in both SIDS and Australia. Additionally, information on the ratification status of international conventions in overseas territories is needed to ensure effective implementation of biosecurity measures and to enable accurate assessment of compliance and governance at the territorial level.

6.6 Final conclusion

Small island developing states face heightened risks from marine invasive species due to their inherent vulnerabilities and heavy reliance on shipping activities. Preventing the introduction and spread of invasive species is resource intensive, and the cost of inaction can be severe, environmentally, economically, and socially. By comparison, Australia's national allocation for pest and disease preparedness and response for 2024–25 is \$123.5 million, with Queensland alone accounting for an estimated \$87.1 million (Commonwealth of Australia 2024). Such levels of investment underscore the magnitude of resources required for managing MIS risks, resources that SIDS are largely unable to mobilise. Australia by contrast, has been among the first countries to recognise the threat posed by MIS and to adopt precautionary biosecurity laws aimed at protecting its biodiversity. For example, Tasmania's Biosecurity Act 2019, Part 1, s.3(c)(iv) provides a regulatory framework that allows reasonable and practicable measures to prevent, eliminate or minimise biosecurity risks even when full scientific certainty is not yet established. This contrast between the vulnerabilities and limited resources of SIDS and the experience-based, precautionary approach implemented by Australia underscores the critical need for stronger, mandatory international environmental instruments that adopt a source-

control approach, alongside enhanced international cooperation, targeted capacity building, and sustainable financing mechanisms.

My work has identified systemic deficiencies in international policy and national capacity that compromise the ability of SIDS to manage MIS, including those introduced via ship biofouling. The findings demonstrate the interconnected vulnerabilities of SIDS, highlighting how fragmented, species-specific responses are insufficient to address the scale and complexity of the threat. I have also provided practical guidance for SIDS to address ship biofouling through the pre-border ship biofouling management framework presented in Chapter 5, as well as actionable guidance in Chapter 2 to strategically align international instruments with specific MIS categories and pathways, promoting consistency, reducing regulatory gaps, and maximising resource efficiency. Drawing on the biosecurity systems framework, the analysis underscores the urgent need for an integrated, precautionary, pre-border approach that shifts the burden of prevention upstream to the sources of risk. Overall, these findings highlight the necessity of binding international biosecurity instruments that enable SIDS to implement robust measures despite limited resources, linking local vulnerabilities to international responsibilities through coordinated, systems-informed strategies. It further argues for a fundamental rethinking of how international biosecurity measures are developed and implemented to ensure both global equity and environmental protection.

6.7 Recommendations

Considering the vulnerabilities, systemic gaps, and capacity constraints identified throughout my thesis, this section presents a set of recommendations to strengthen marine biosecurity in SIDS. My recommendations are to implement the following measures to build capacity that will enhance national and regional preparedness and contribute to improved global biosecurity by reducing transboundary risks:

- Pre-border biosecurity measures that target the primary sources and pathways of MIS should be prioritised, because, as demonstrated in my research, this approach provides the most resource-efficient and effective protection for SIDS. By addressing biosecurity risks upstream, pre-border controls reduce reliance on resource-intensive post-border responses that exceed the institutional and financial capacity of many SIDS. The guidance developed in Chapters 2 and 5 supports the practical implementation of this approach, while the biosecurity systems and regulatory frameworks examined in Australia provide a scalable model that SIDS can adapt in accordance with national capacity, rather than developing new systems from the outset.
- A lead agency with clearly defined roles and responsibilities for all stakeholders, including their financial and in-kind contributions, as well as provisions for data sharing, transparency, and a

sustainable funding mechanism should be established to ensure continuity of the biosecurity system. This action is necessary because raising awareness is the first and most critical step in preparing for MIS management, yet limited resources and the concentration of biosecurity responsibilities at the government level constrain effectiveness. By implementing this lead agency and supporting resource-intensive activities, such as research and risk assessments, through partnerships with local and regional universities and citizen science communities (including the public and NGOs), national capacity is strengthened, knowledge development is promoted, and ongoing monitoring and reporting are effectively maintained.

- Targeted training and capacity building initiatives should be provided, facilitated by relevant UN agencies (e.g., the International Maritime Organization) in collaboration with capable partner countries (e.g., Australia), to support SIDS in establishing and maintaining effective pre-border biosecurity systems. This is necessary because, although pre-border biosecurity represents the most effective approach and this study provides guidance and supporting materials, the development of such systems requires considerable investment that many SIDS are unable to meet independently. By delivering regional workshops in collaboration with relevant regional organisations, training can be made accessible, context-appropriate, and aligned with the shared needs and capacities of SIDS, thereby enhancing specialised skills, strengthening national and regional capacity, and enabling the sustainable implementation of pre-border biosecurity measures.
- Regional early warning surveillance systems for MIS using shared eDNA databases, building on programs such as the Queensland Seaports Environmental DNA (eDNA) Surveillance program (Q-SEAS) as an example should be developed. This action is necessary because establishing species-specific primers and monitoring systems is highly resource intensive and time consuming, making independent implementation largely unaffordable for many SIDS. By pooling resources regionally and sharing databases, countries can implement effective surveillance, facilitate reporting, and promote coordinated regional protection initiatives, thereby improving early detection and reducing the transboundary risks of MIS.
- Greater independent decision-making authority to overseas SIDS territories to enable more effective marine biosecurity governance should be granted. This action is necessary because jurisdictional dependency, an identified barrier to managing MIS, jeopardises these territories' marine ecosystems and the services they provide. Overseas territories also do not automatically become parties to international conventions ratified by their sovereign states, and treaties must often be explicitly extended through national legislation. Without such authority, overseas SIDS are restricted in their ability to safeguard local environments. By granting this independence, overseas territories can implement timely, context-specific biosecurity

measures, strengthen local environmental protection, and contribute more effectively to regional marine biosecurity governance.

- SIDS geographical groupings should be restructured to optimise regional support and enable more coherent biosecurity strategies. This action is necessary because MIS are a transboundary issue, and policy and regulatory decisions taken by one country can affect others regionally and globally. The current *UN geographical grouping of SIDS* creates barriers to coordinated strategies and standardised approaches. Caribbean and Pacific SIDS benefit from geographic proximity and regional cooperation, whereas AIS SIDS, located across the Atlantic, Indian Ocean, and South China Seas, face weaker capacity due to greater dispersion and limited collaboration. Implementing revised groupings would improve access to regional support, strengthen coordination, and facilitate the development of standardised approaches, thereby enhancing regional and international effectiveness in managing MIS. The proposed revised groupings and potential supporting regional organisations are presented in Table 6.2.
- Stronger, mandatory international environmental instruments that adopt a precautionary, source-control, and polluter-pays principle approach should be developed and established. This action is necessary because environmental challenges such as marine invasive species involve significant uncertainties and complexities, making it difficult to establish clear causal links, and reactive measures can be resource-intensive and ineffective. The upcoming IMO convention on ship biofouling presents a prime opportunity to embed fairness and equity into international maritime regulations, enabling resource-limited states such as SIDS to effectively protect their vulnerable marine ecosystems. Consistent with this, international standards should mandate that vessels clean their hulls before departing from the port and allow only controlled in-water hull grooming measures, thereby minimising the risk of transporting marine invasive species across regions and supporting a precautionary, source-control approach.

Table 6.2 *Proposed restructuring of geographical groupings for Small Island Developing States, including potential regional organisations capable of supporting biosecurity coordination.*

SIDS Geographical Distribution Groupings	Small Island Developing States	Potential Regional Organisations that could provide support to SIDS within each geographical grouping
Asia-Pacific SIDS	Cook Islands, Fiji, Kiribati, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu, American Samoa, Cook Islands, French Polynesia, Guam, New Caledonia, Niue, Northern Mariana Islands, Singapore	Secretariat of the Pacific Regional Environment Programme (SPREP); Partnerships in Environmental Management for the Seas of East Asia (PEMSEA)
Caribbean SIDS	Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Anguilla, Aruba, Bermuda, Cayman Islands, Curacao, Guadeloupe, Martinique, Montserrat, Puerto Rico, Sint Maarten, Turks and Caicos Islands, British Virgin Islands, U.S. Virgin Islands	Caribbean Invasive Species Network; Dutch Caribbean Nature Alliance
Atlantic SIDS	Cabo Verde, Guinea-Bissau, Sao Tomé and Príncipe	Mediterranean Science Commission (CIESM); European Alien Species Information Network (EASIN)
Indian Ocean SIDS	Comoros, Maldives, Mauritius, Seychelles	Western Indian Ocean Network on Invasive Species (WIONIS); Indian Ocean Rim Association (IORA)

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Appendix A

Associated to Chapter 1 “General Introduction - Marine Invasive Species Management: A Critical and Complex Global Issue”.

Table A1 Examples of toxin-producing marine invasive species and their toxicological risks on human health.

SN	Toxin-producing marine invasive species	Toxicological risks on human health
1	Silver-cheeked puffer or Silverstripe blaasop (<i>Lagocephalus sceleratus</i>)	It contains toxic amounts of the tetrodotoxin TTX that causes nerve and muscle paralysis (Narahashi 2001), with the potential for severe poisonings of uninformed consumers like tourists.
2	Striped eel catfish (<i>Plotosus. lineatus</i>)	Its venom generates instant excruciating pain, followed by cyanosis, numbness and swelling (Bedry et al. 2021).
3	Lionfish (<i>Pterois miles</i>) and red lionfish (<i>Pterois volitans</i>)	Their stings generate immediate pain that can last for 6–12 hours, and can lead to ulceration of the wound site, muscle cramps, headaches, nausea, or diarrhoea (McGuire and Hill 2021; Resiere et al. 2016; Ruiz-Carus et al. 2006)
4	Marbled spinefoot (<i>Siganus rivulatus</i>) and the dusky spinefoot (<i>Siganus luridus</i>)	Their venom generates immediate and intense localised pain and instantaneous swelling (Bedry et al. 2021) and the ingestion the dusky spinefoot’s flesh may generate symptoms like burning pain in the throat, followed by tingling and muscle cramps, electric shock sensation, nightmares, hallucinations,

		agitation, anxiety and nausea of varying severity persisting between 12 and 30 hours before disappearing completely (Herzberg 1973; Raikhlin-Eisenkraft and Bentur 2002).
5	Stonefish, (<i>Synanceia verrucosa</i>)	Envenomation by the stonefish causes immediate, intense, and radiating pain resulting in unconsciousness and gross edema of the affected limb. If untreated, the pain peaks 60 to 90 minutes after the sting and lasting up to 12 hours and sometimes for days. The stonefish venom also causes pallor, diaphoresis, nausea, muscle weakness, dyspnoea, headaches and delirium. Rare cases of severe systemic morbidity and deaths have also been reported (Auerbach 1991; Lee, Teoh and Leo 2004).
6	Jellyfish schyphomedusa (<i>Rhopilema nomadica</i>)	Their stings provoke intense pain instantly, followed by redness and skin rashes due to inflammatory reactions and first-degree burning sensations (Uri, Marina and Liubov 2005).
7	Hydroid (<i>Macrorhynchia philippina</i>)	Its venom causes instant burning sensation with pain ranging from mild to severe, followed by red itching rashes that may last up to ten days before fading (Çinar et al. 2006; Rifkin, Fenner and Williamson 1993).
8	Long-spined urchin (<i>Diadema setosum</i>)	Punctured injuries from the long-spined urchin causes local pain, swelling that persisted a few days, granuloma formation due to inflammatory reactions and massive synovitis and systemic illness (Cracchiolo and Goldberg 1977).

Appendix B

Associated to Chapter 2 “*Leveraging existing international policy instruments to manage marine invasive species and their introduction pathways*”.

Table B1 *Inclusion and exclusion criteria used for screening the relevant document.*

Inclusion Criteria	Exclusion Criteria
Include studies only published in English.	Exclude studies published in languages other than English.
Include documents that focus on international policy instruments addressing marine invasive species.	Exclude studies that primarily focus on experimental research or effectiveness testing of monitoring technologies.
Include studies analysing policy implementation or governance challenges related to marine invasive species.	Exclude articles that are purely ecological assessments of marine invasive species without a policy focus.
Include documents discussing institutional frameworks and international cooperation on marine biosecurity.	Exclude national or local policies that do not have an international or regional component.
	Exclude technical reports on species identification, detection methods, or case studies unrelated to policy discussions.
	Exclude studies and reports on pathogens, viruses, or medical health aspects that are not related to marine invasive species.

Table B2 Search strings utilised when searching Web of Science (WoS), SCOPUS, James Cook University Library databases and Google search engine for literature related to international policy instruments addressing marine invasive species.

Keywords & Phrases	Synonyms and search string
Marine Invasive Species	("Marine Invasive Species" OR "Invasive Marine Species" OR "Introduced Aquatic Species" OR "Introduced Marine Species" OR "Invasive Aquatic Species" OR "Aquatic Invasive Species" OR "Alien Aquatic Species" OR "Alien Marine Species" OR "Marine Pests" OR "Aquatic pests" OR "Non-native Aquatic Species" OR "Non-native Marine Species" OR "Exotic Marine species" OR "Exotic Aquatic Species" OR "Biofouling Organisms" OR "Harmful Aquatic Species" OR "Harmful Marine Species" OR "Non-indigenous Aquatic species" OR "Non-indigenous Marine Species" OR "Pathogens" OR "Infectious Agents" OR "Living Modified Organisms" OR "Microbial" OR "Viruses" OR "Parasites" OR "Genetically Modified Organisms" OR "Foreign Organisms")
International Policy Instruments	("International Policy Instruments" OR "International regulations" OR "international biosecurity policies" OR "International agreements" OR "international treaties" OR "International Protocols" OR "International Legal Mechanisms" OR "International Guidelines" OR "Binding International Regulations" OR "International Governance Agreements" OR "Global protocols" OR "Global Regulatory Frameworks" OR "Global Governance Tools" OR "Global Policy Frameworks")

Table B3 *Exclusion criteria applied to the results from the Web of Science (WoS), SCOPUS, James Cook University Library databases, and Google search engine for literature on international policy instruments addressing marine invasive species. "N/A" denotes that the filter was not available in the respective database.*

	Web of Science	Scopus	JCU Library	Grey Literature
Language	English			
Publication Type	Articles, Reviews, Books, Book Chapters, Conference Papers	Articles, Reviews, Books, Book Chapters, Conference Papers	Articles, Reviews, Books, Book Chapters, Conference Papers, Theses, Technical Reports, Reports,	Articles, Reviews, Books, Book Chapters, Conference Papers, Theses, Technical Reports, Reports,
Publication stage	N/A	Final	N/A	N/A
Subject area	Environmental Sciences Ecology, Food Science Technology, Agriculture, Biodiversity Conservation, Marine Freshwater Biology, Parasitology, Social Sciences Other Topics, Toxicology, Veterinary Sciences	Agricultural and Biological science, Biochemistry, Genetics and molecular Biology, Environmental science, Multidisciplinary, Earth and planetary science, Social science, Veterinary	Invasive species, Introduced species, Indigenous Species, Harbours, Nonnative Species, Marine & Freshwater Biology, Biodiversity Conservation, Harbors, alien, Introduced Organisms Control, marine pests, aquatic pests, microorganisms, Pathogens, Animals	No filter applied but results were screened using the same subject areas as WoS and Scopus
Date	January 2019 – December 2024			

Table B4 *Compilation of Terminology, Introduction Pathways, Types of Introductions, Nature of implemented policy measures and their Scope.*

Guide/Convention/Protocol	Term used	Introduction Type	Pathway addressed	Nature of Measures	Scope of Measures	Relevance
International Plant Protection Convention 1951	Plant pests	Primary introduction	International transportation	Preventive	Specific	Not Relevant - Terrestrial plant pests not marine
Convention on the Facilitation of International Maritime Traffic (FAL) as amended 1965	Diseases or pests	Primary & Secondary introduction	Trade measures to prevent the introduction or spread of diseases or pests.	Preventive	General	Indirect Relevance
Convention on International Trade in Endangered Species (CITES) 1973	animals and plants	Primary introduction	International trade of wild fauna and flora	Preventive	General	Indirect Relevance
International Convention for Safety of Life at Sea (SOLAS) as amended including the ISM Code 1974	No mention as not addressing MIS directly, but through ship construction and management.	Primary & Secondary introduction	Shipping	Preventive	General	Indirect Relevance
Convention on the Conservation of Migratory Species of Wild Animals (CMS) 1979	Animals – introduced exotic species	Primary & Secondary introduction	No specific pathway - only mentions strictly controlling the introduction of, or controlling or	Preventive & Corrective	General	Indirect Relevance

			eliminating, already introduced exotic species.			
United Nations Convention on the Law of the Sea (UNCLOS) 1982	alien or new species	Primary introduction	No specific pathway	Preventive	General	Direct relevance
MARPOL 73/78, Annex IV 2003 & Annex V 1988	No mention as not addressing MIS directly (Sewage and Garbage)	Primary introduction	Shipping - Sewage and Garbage	Preventive	General	Indirect Relevance
Convention on Biological Diversity (CBD) 1992	Alien species & living modified organisms, microbial	Primary introduction	Trade and release of living modified organisms and general introduction of alien species.	Preventive & Corrective	General	Direct relevance
Rio Declaration and Agenda 21 1992	Rio D - No mention of MIS or IAS but mentions the global and transboundary environmental issues. Agenda 21 - Pests in agriculture and non-indigenous organisms in ballast water	Primary introduction	Trade and Shipping via ballast water discharge and indirectly biofouling through anti-fouling paints	Preventive	General	Direct relevance

General Agreement on Tariffs and Trade (GATT) 1994	animal or plant life	Primary introduction	International trade	Preventive	General	Indirect Relevance
WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) 1995	Pest or disease	Primary introduction	International trade	Preventive	Specific	Indirect Relevance
FAO Code of Conduct for Responsible Fisheries and subsequent Technical Guidelines 1995	non-indigenous, non-native species and genetically altered stocks	Primary & Secondary introduction	Introduction for aquaculture	Preventive & Corrective	Specific	Direct relevance
FAO Code of Conduct for the import and release of exotic biological control agents 1995	exotic biological control agents, pests- Any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products	Primary	Agriculture, Trade,	Preventive	Specific	Not Relevant - Terrestrial not marine
UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities 1995	invasive species	Primary	land-based activities	Preventive	General	Indirect Relevance

Agreement for the Implementation of the Provisions of UNCLOS relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) 1995	waste, discards, non-target species, catch by lost or abandoned gear,	Primary	Discarded material (Waste/abandoned gears) from fishing vessels	Preventive	Specific	Indirect Relevance
London Convention 1972 & London Convention Protocol 1996	No mention as not addressing MIS directly (Sewage and Waste)	Primary introduction	Shipping - Sewage and Waste	Preventive	General	Indirect Relevance
FAO guidelines on Precautionary Approach to Capture Fisheries (Including Species Introductions) 1996	Parasites, diseases, pests, genetically modified organisms	Primary & Secondary introduction	Introduction for aquaculture	Preventive & Corrective	Specific	Direct relevance
Convention on the Law of Non-navigational Uses of International Watercourses 1997	Alien or new species	Primary & Secondary introduction	No specific pathway - only mentions the introduction of alien species	Preventive	General	Direct relevance
International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) and the Seafarer's Training, Certification and Watchkeeping Code (STCW Code) 1978/95/97	No mention of IAS or MIS (training of seafarers to prevent marine pollution from ships)	Primary	Shipping	Preventive & corrective	General	Indirect Relevance

Convention on International Civil Aviation (Resolution A-32-9 Preventing the Introduction of Invasive Alien Species) 1998	Invasive alien species	Primary	Airplanes	Preventive	General	Direct relevance
IUCN Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species 2000	Alien invasive species, non-native, non-indigenous, foreign, exotic, any part, gametes or propagule that might survive and subsequently reproduce	Primary & Secondary introduction	Trade, Travel and Transportation, release and Aquaculture	Preventive & Corrective	Specific	Direct relevance
Cartagena Protocol on Biosafety 2000	living modified organisms, viruses and viroids	Primary introduction	International Trade, Transport and accidental releases	Preventive	Specific	Direct relevance
The Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2001	introduced non- native animals, plants, hybrids or disease-causing organisms.	Primary	No Specific Pathway	Preventive	General	Indirect Relevance

International Convention on the Control of Harmful Anti-fouling Systems on Ships (Anti-Fouling Convention) 2001	No mention as not addressing MIS directly	Primary & Secondary introduction	Shipping - hull fouling	Preventive	Specific	Indirect Relevance
RAMSAR (Resolution VIII.18 Invasive species and wetlands) 2002	aquatic invasive species or invasive alien species or invasive species	Primary & Secondary introduction	Movement or Trade of New Species	Preventive	General	Direct relevance
Codex Alimentarius (Code of Practice for Fish and Fishery Products) 2003	Pathogens, diseased fish, parasites, undesirable microorganisms, Pathogenic bacteria, viruses, biological hazard	Primary introduction	Trade, Aquaculture	Preventive	Specific	Direct relevance
International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004	Harmful Aquatic Organisms and Pathogens	Primary introduction	Shipping - Ballast water and sediments.	Preventive & Corrective	Specific	Direct relevance
International Health Regulations (IHR) and plant and animal health agreements 2005	Infectious agent and Pathogens	Primary & Secondary introduction	International travel, transportation and trade	Preventive & Corrective	Specific	Indirect Relevance

ICES Code of Practice on the Introduction and Transfer of Marine Organisms 2005	Disease agent, parasites, genetically modified organisms, non-indigenous species, exotic species,	Primary & Secondary introduction	Trade, Travel and Transportation, release and Aquaculture	Preventive & Corrective	Specific	Direct relevance
FAO guide: Aquaculture development. 2. Health management for responsible movement of live aquatic animals. 2007	animals, pathogens, exotic species	Primary & Secondary introduction	Introduction for aquaculture	Preventive & Corrective	Specific	Direct relevance
FAO guide: Aquaculture development. 6. Use of wild fishery resources for capture-based aquaculture. 2011	disease, parasites or genetic material (eggs or seed in most cases, but include broodstock in some operations)	Primary & Secondary introduction	Introduction for aquaculture	Preventive & Corrective	Specific	Direct relevance
World Organisation for Animal Health (OIE)'s Guidelines for assessing the risk of non-native animals becoming invasive. 2012	Non-native (or alien) animal, pathogens, invasive non-native species, hazard (non-native animal)	Primary & Secondary introduction	Trade, Shipping, Transportation	Preventive & Corrective	Specific	Direct relevance

IMO Guidance for Minimizing the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft 2012	invasive aquatic species as biofouling, invasive aquatic organisms	Primary & Secondary introduction	Shipping	Preventive	Specific	Direct relevance
IMO Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species 2023	Invasive aquatic species, Biofouling, aquatic organisms such as microorganisms, plants and animals including pathogens	Primary introduction	Shipping, hull fouling	Preventive & Corrective	Specific	Direct relevance
Manual of Diagnostic Tests and Vaccines for Terrestrial Animals 2024	diseases, viruses, bacteria, parasites, pathogens	Primary & Secondary introduction	Trade	Preventive & Corrective	Specific	Not Relevant - Terrestrial not marine
Terrestrial Animal Health Code 2024	diseases, pathogenic agents, Zoonoses, biological products, hazard, germinal products	Primary & Secondary introduction	Trade, transport by air, land and sea	Preventive & Corrective	Specific	Not Relevant - Terrestrial not marine
Manual of Diagnostic Tests for Aquatic Animals 2024	disease or pathogen, virus, bacteria,	Primary & Secondary introduction	Aquaculture	Preventive & Corrective	Specific	Direct relevance

	parasites, fungi, protists					
The Aquatic Animal Health Code 2024	pathogenic agent (via aquatic animals, aquatic animal products, vectors or fomites)	Primary & Secondary introduction	Introduction for aquaculture and Trade	Preventive & Corrective	Specific	Direct relevance

Table B5 *Identified limitations in current international policy instruments.*

International Policy Instrument	Identified Limitations
Convention on the Facilitation of International Maritime Traffic (FAL) as amended 1965	Indirect relevance - Supports efficient port operations and clearance processes, with incidental benefits for invasive species prevention.
Convention on International Trade in Endangered Species (CITES) 1973	Indirect relevance – Aims to prevent species over-exploitation through international trade regulation, with incidental benefits for invasive species prevention through comprehensive documentation and permitting requirements for listed species.
International Convention for Safety of Life at Sea (SOLAS) as amended including the ISM Code 1974	Indirect relevance - Focuses on ship safety and operations, with incidental benefits for invasive species prevention through improved vessel management.

Convention on the Conservation of Migratory Species of Wild Animals (CMS) 1979	Limited scope and coverage - limited to protecting migratory species against invasive species.
United Nations Convention on the Law of the Sea (UNCLOS) 1982	Limited scope and coverage - Establishes broad obligations for marine protection but lacks specific provisions for invasive species and depends on external mechanisms for enforcement.
MARPOL 73/78, Annex IV 2003 & Annex V 1988	Indirect relevance - Focuses on prevention of pollution from garbage and sewage from ships, with incidental benefits for invasive species prevention through management plans and record-keeping requirements.
Convention on Biological Diversity (CBD) 1992	Limited scope and coverage - Offer very general principles for identification and monitoring and does not provide specific mechanisms, protocols, or detailed guidance for the practical management of MIS.
Rio Declaration and Agenda 21 1992	Limited scope and coverage - General measures and the guides are not legally binding (voluntary)
General Agreement on Tariffs and Trade (GATT) 1994	Focuses on international trade, with incidental benefits for invasive species prevention through regulate measures applied to traded goods.
WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) 1995	Focuses on international trade, with incidental benefits for invasive species prevention through regulated measures applied to traded goods.
UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities 1995	Limited scope and coverage - General measures and the guides are not legally binding (voluntary)

Agreement for the Implementation of the Provisions of UNCLOS relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) 1995	Indirect relevance – Focuses on minimising pollution, waste, discards, catch by lost or abandoned gear, catch of non-target species, both fish and non-fish species, with incidental benefits for invasive species prevention through fisheries management.
London Convention 1972 & London Convention Protocol 1996	Indirect relevance - Focuses on pollution prevention from dumping of wastes, with incidental benefits for invasive species prevention through management plans and record-keeping requirements.
Convention on the Law of Non-navigational Uses of International Watercourses 1997	Limited scope and coverage - General nature and the lack of specific, actionable measures.
International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) and the Seafarer's Training, Certification and Watchkeeping Code (STCW Code) 1978/95/97	Indirect relevance - Focuses on seafarer training to ensure safety and prevent pollution, with incidental benefits for invasive species prevention through general environmental awareness for seafarers.
Convention on International Civil Aviation (Resolution A-32-9 Preventing the Introduction of Invasive Alien Species) 1998	Limited scope and coverage - General nature and the lack of specific, actionable measures.
The Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2001	Limited scope and coverage - limited to protecting Albatross and Petrels against invasive species.
International Convention on the Control of Harmful Anti-fouling Systems on Ships (Anti-Fouling Convention) 2001	Indirect relevance – Focuses on pollution prevention from the use of harmful chemical compounds used in anti-fouling systems, with incidental benefits for invasive species prevention through management plans and record-keeping requirements.

RAMSAR (Resolution VIII.18 Invasive species and wetlands) 2002	Limited scope and coverage - General nature and the lack of specific, actionable measures.
Codex Alimentarius (Code of Practice for Fish and Fishery Products) 2003	Voluntary - The guides are not legally binding
FAO guide: Aquaculture development. 2. Health management for responsible movement of live aquatic animals. 2007	Voluntary - The guides are not legally binding
FAO guide: Aquaculture development. 6. Use of wild fishery resources for capture-based aquaculture. 2011	Voluntary - The guides are not legally binding
World Organisation for Animal Health (OIE)'s Guidelines for assessing the risk of non-native animals becoming invasive. 2012	Limited scope and coverage - Only assesses the risk of non-native animals becoming invasive and the guides are not legally binding (voluntary)
IMO Guidance for Minimizing the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft 2012	Voluntary - The guides are not legally binding
IMO Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species 2023	Voluntary - The guides are not legally binding

S1. Supporting information

Supplementary datasets used in this chapter are provided in the accompanying Excel workbook.

Appendix C

Associated to Chapter 3 “Adequacy of international policy instruments in safeguarding Small Island Developing States from marine invasive species threat”.

Table C1 *Conceptual Framework for analysing the adequacy of International Instruments relevant to Small Island Developing States. Criteria not being met are shown in italic.*

Guide/Convention/Protocol	Criteria for Ecological Threats, Livelihood implications & Resource Availability						Overall Adequacy
	Address Primary/ secondary introduction Pathways	Mitigates impacts of MIS & Protects livelihood	Preventive/ Corrective Measures	Voluntary/ Mandatory measures	Accountability	Feasibility with regards to resource implications	
Convention on the Facilitation of International Maritime Traffic (FAL) as amended 1965	Both - Trade	<i>YES (indirect) - simplify maritime documentation and procedures to promote efficiency in trade, indirectly addressing MIS.</i>	Preventive	Mandatory/ General measures	<i>Moderate Accountability</i>	Feasible with minimal resources, no direct cost for implementation in SIDS.	Moderate
Convention on International Trade in	Primary - Trade of wild	<i>YES (indirect) - Primarily focuses on endangered species</i>	Preventive	Mandatory/ General measures	High Accountability	Feasible for SIDS, minimal resource requirements.	Moderate

Endangered Species (CITES) 1973	fauna and flora	<i>trade. Potential invasiveness if trade species is released.</i>					
International Convention for Safety of Life at Sea (SOLAS) as amended including the ISM Code 1974	Both - Shipping	<i>YES (indirect) - Focus on maritime safety; indirect relevance to invasive species through ship construction and management.</i>	Preventive	Mandatory/ General measures	High Accountability	<i>Requires resources for implementation; feasible with support.</i>	Moderate
Convention on the Conservation of Migratory Species of Wild Animals (CMS) 1979	Both - No specific pathway	<i>YES (indirect) – Protects ecosystems of migratory species from invasive species.</i>	Both	Mandatory/ General measures	Moderate Accountability	Feasible with moderate resources and international support.	Moderate
United Nations Convention on the Law of the Sea (UNCLOS) 1982	Primary - No specific pathway	YES - Supports MIS prevention through ocean governance.	Preventive	Mandatory/ General measures	Moderate Accountability	<i>Resource-intensive monitoring and enforcement may challenge SIDS.</i>	Moderate
MARPOL 73/78, Annex IV 2003 & Annex V 1988	Primary - Sewage & Garbage	<i>YES – Indirectly addresses the primary introduction</i>	Preventive	Mandatory/ General measures	High Accountability	<i>High resource demand for reception &</i>	Moderate

		<i>of species via Sewage & Garbage</i>				<i>treatment facilities to control pollution.</i>	
Convention on Biological Diversity (CBD) 1992	Primary - Trade and release	YES - Focus on living modified organisms and viruses, some direct relevance to invasive species.	Both	Mandatory/ General measures	<i>Moderate Accountability</i>	<i>Feasible with international support, includes provisions for financial/technical assistance.</i>	Moderate
Rio Declaration and Agenda 21 1992	Primary – Trade and ballast water	YES - Provides framework for sustainable development, addresses MIS in ballast water.	Preventive	<i>Voluntary/ General measures</i>	<i>Low Accountability</i>	Feasible with international support.	Moderate
General Agreement on Trade and Tariffs (GATT) 1994	Primary - Trade	<i>YES (indirect) - Focuses on trade of animal and plant species that might become invasive if released.</i>	Preventive	Mandatory/ General measures	<i>Low to Moderate Accountability</i>	Feasible for SIDS, low implementation cost.	Moderate

WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) 1995	Primary - Trade	YES - Addresses biosecurity in relation to agriculture and trade, relevant for preventing species introduction.	Preventive	Mandatory/ Specific measures	High Accountability	<i>Feasible with international cooperation, includes provisions for financial/technical assistance.</i>	Moderate
FAO Code of Conduct for Responsible Fisheries and subsequent Technical Guidelines 1995	Both - Introduction for aquaculture	YES - Directly addresses species introduction in fisheries and biosecurity.	Both	<i>Voluntary/</i> Specific measures	<i>Low Accountability</i>	Feasible with moderate resources.	Moderate
UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities 1995	Primary – Land-based activities	YES – Indirectly addresses the primary introduction of species via land-based activities	Preventive	<i>Voluntary/</i> General measures	<i>Moderate Accountability</i>	<i>Requires significant financial resources, but feasible with international cooperation.</i>	Low
Agreement for the Implementation of the Provisions of UNCLOS relating to the	Primary – Waste, discard, lost	<i>YES – Indirectly preventing the spread of invasive species through</i>	Preventive	Mandatory/ Specific measures	High Accountability	<i>Requires, significant financial and technical support,</i>	Moderate

Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) 1995	or abandoned gear	<i>discarded material from fishing vessels</i>				<i>but feasible with international cooperation.</i>	
London Convention 1972 & London Convention Protocol 1996	Primary - Sewage & Waste	<i>YES - Indirectly preventing the spread of invasive species through waste</i>	Preventive	Mandatory/ General measures	<i>Moderate Accountability</i>	<i>Monitoring and enforcement costs may pose challenges to SIDS.</i>	Low
FAO guidelines on Precautionary Approach to Capture Fisheries (Including Species Introductions) 1996	Both - Introduction for aquaculture	YES - Addresses precautionary measures in fisheries management to mitigate risks of invasive species.	Both	<i>Voluntary/ Specific measures</i>	<i>Low Accountability</i>	<i>Resource requirements vary; feasible with appropriate support.</i>	Low
Convention on the Law of Non-navigational Uses of International Watercourses 1997	Both - No specific pathway	YES - Promotes equitable and reasonable use of international watercourses &	Preventive	Mandatory/ General measures	<i>Low Accountability</i>	Feasible with moderate resources.	Moderate

		introduction of invasive species.					
International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) and the Seafarer's Training, Certification and Watchkeeping Code (STCW Code) 1978/95/97	Primary - Shipping	<i>YES (indirect) – Focuses on seafarers training to ensure safety and prevent pollution.</i>	Both	Mandatory/ General measures	High Accountability	<i>Requires resources, particularly in the form of technical assistance and training.</i>	Moderate
Convention on International Civil Aviation (Resolution A-32-9 Preventing the Introduction of Invasive Alien Species) 1998	Primary- Travel and transportation	Yes - Urges all Contracting States to help reduce the risk of introducing potentially invasive species.	Preventive	<i>Voluntary/ General measures</i>	<i>Low Accountability</i>	<i>High resource demands for compliance.</i>	Low
IUCN Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species 2000	Both – Trade, travel, transportation, aquaculture and release	YES - Directly addresses biodiversity loss due to invasive species.	Both	<i>Voluntary/ Specific measures</i>	<i>Low Accountability</i>	<i>Requires resources for implementation; feasible with support.</i>	Low

Cartagena Protocol on Biosafety 2000	Primary – Trade, travel, transportation and releases	YES - Focus on living modified organisms and viruses, some direct relevance to invasive species.	Preventive	Mandatory/ Specific measures	Moderate Accountability	<i>Feasible with international aid, preventive measures for biosecurity.</i>	Moderate
The Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2001	Primary - No specific pathway	<i>YES indirect) - Protects Albatross and Petrels against invasive species.</i>	Preventive	Mandatory/ General measures	High Accountability	<i>Requires significant resources, particularly in terms of capacity building and financial support.</i>	Moderate
International Convention on the Control of Harmful Anti-fouling Systems on Ships (Anti-Fouling Convention) 2001	Both – Hull fouling	YES - Protects marine environment/ resources from the adverse effects of harmful substances in anti-fouling systems	Preventive	Mandatory/ Specific measures	High Accountability	Feasible for SIDS but may require external funding or technical assistance.	High
RAMSAR (Resolution VIII.18 Invasive species and wetlands) 2002	Both - Movement or	YES - Directly addresses invasive species in wetlands.	Preventive	<i>Voluntary/</i> General measures	<i>Low</i> Accountability	Feasible with moderate resources, requires	Moderate

	Trade of New Species					technical support for SIDS.	
Codex Alimentarius (Code of Practice for Fish and Fishery Products) 2003	Primary – Trade, aquaculture	Yes – Prevents invasive species introduction through robust food safety management systems and monitoring.	Preventive	Voluntary/ Specific measures	Moderate Accountability	<i>Requires substantial financial, technical, and human resources</i>	Low
International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004	Primary – Shipping (Ballast water & sediments)	YES – prevents introduction of invasive species via ballast water	Both	Mandatory/ Specific measures	High Accountability	<i>High resource demands for compliance (technology for treatment, reception facilities etc), SIDS may require financial or technical assistance.</i>	Moderate
International Health Regulations (IHR) and plant and animal health agreements 2005	Both – Trade, travel and transportation	<i>YES - Addresses biosecurity, indirect relevance to invasive marine species.</i>	Both	Mandatory/ Specific measures	Low Accountability	<i>Feasible with existing biosecurity frameworks,</i>	Low

						<i>especially with international support.</i>	
ICES Code of Practice on the Introduction and Transfer of Marine Organisms 2005	Both - Trade, travel, transportation, aquaculture and release	YES - Directly addresses primary and secondary introductions of invasive species.	Both	<i>Voluntary/ Specific measures</i>	<i>Low Accountability</i>	<i>Feasible with international cooperation but may need additional resources for compliance.</i>	Low
FAO guide: Aquaculture development. 2. Health management for responsible movement of live aquatic animals. 2007	Both - Introduction for aquaculture	YES - Addresses health management to prevent the introduction of diseases and invasive species in aquaculture.	Both	<i>Voluntary/ Specific measures</i>	<i>Low Accountability</i>	<i>Requires resources for implementation; feasible with support.</i>	Low
FAO guide: Aquaculture development. 6. Use of wild fishery resources for capture-based aquaculture. 2011	Both - Introduction for aquaculture	YES - Addresses potential risks of invasive species and diseases/pathogens through the use of wild fish.	Both	<i>Voluntary/ Specific measures</i>	<i>Low Accountability</i>	<i>Resource feasibility varies; support needed for implementation.</i>	Moderate

World Organisation for Animal Health (OIE)’s Guidelines for assessing the risk of non-native animals becoming invasive. 2012	Both - Trade, Shipping, Transportation	YES - assesses the risk of non-native animals becoming invasive	Both	<i>Voluntary/ Specific measures</i>	<i>Moderate Accountability</i>	<i>Requires significant financial, technical, and human resources.</i>	Low
IMO Guidance for Minimizing the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft 2012	Both - Shipping	YES - invasive aquatic species as biofouling.	Preventive	<i>Voluntary/ Specific measures</i>	<i>Moderate Accountability</i>	<i>Requires significant financial, technical, and human resources.</i>	Low
IMO Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species 2023	Primary – Shipping (Hull fouling)	YES - However, cleaning with capture is not recommended for Rating 1 – microfouling, which might contain pathogens.	Both	<i>Voluntary/ Specific measures</i>	<i>Moderate Accountability</i>	<i>Feasible with moderate resources, especially with international assistance.</i>	Low
Manual of Diagnostic Tests for Aquatic Animals 2024	Both - Aquaculture	YES – Provides specific diagnostic procedures for	Both	<i>Voluntary/ Specific measures</i>	<i>Low Accountability</i>	<i>Requires significant financial,</i>	Low

		diseases in aquatic animals, addressing invasive species.				<i>technical, and human resources.</i>	
The Aquatic Animal Health Code 2024	Both – Trade and Introduction for aquaculture	YES - Provides a framework for managing health risks in aquatic animals, addressing invasive species.	Both	<i>Voluntary/ Specific measures</i>	<i>Moderate Accountability</i>	Feasible with adequate resources.	Moderate

Appendix D

Associated to Chapter 4 “Preparedness of Small Island Developing States for managing marine invasive species introduction via ship biofouling”.

Table D1 Data Source for Small Island Developing States Preparedness Assessment.

SN	DATA SOURCE
1	Surveys and interviews (2023-2024)
2	Abdulla A, Floerl O, Richmond M, Johnston O, Bertzky M, Birch S and Walsh A (2007) Enhanced detection and management of marine introduced species in the Seychelles. Final project report, IUCN Global Marine Program, Gland, Switzerland. www.iucn.org .
3	Agard J, St. Louis A and Boodram N (2023) <i>Grenada National Ecosystem Assessment</i> , St. Georges, Grenada; Barataria, Trinidad and Tobago.
4	Aruga J, Opu J, Bongro M and Kumul C (2019) <i>Papua New Guinea National Biodiversity Strategic Action Plan 2019–2024</i> , Conservation and Environment Protection Authority (CEPA), Port Moresby, Papua New Guinea.
5	Barbados Maritime Ship Registry (2020) <i>Bulletin 332: Electronic record keeping systems</i> . Barbados Maritime Ship Registry, Executive Agency of the Barbados Government, Bridgetown, Barbados.
6	Belize Port Authority (2018) <i>Marine Circular No. 01/2018: Belize Port Authority environmental protection guideline</i> . Belize Port Authority,, Belize City, Belize.
7	Biosecurity Authority of Fiji (BAF) <i>Partnership with DHI – Vessel Check to strengthen BAF monitoring process</i> .
8	Butler D (2017) <i>Fifth National Report to the Convention on Biological Diversity</i> , National Environment Service, Cook Islands, Rarotonga, Cook Islands.
9	Chase V, Felix M-L, Mathurin G, John L, Andrew GM, Lewis D and Krauss U (2011) <i>Saint Lucia National Invasive Species Strategy 2012–2021</i> .
10	Debrot AO, van Buurt G and Vermeij MJA (2011) <i>Preliminary overview of exotic and invasive marine species in the Dutch Caribbean</i> , C188/11, The Hague, The Netherlands.
11	Department of Environment, Government of Fiji, (2020) <i>National Biodiversity Strategy and Action Plan 2020–2025</i> , Suva, Fiji.
12	Department of Environment Protection and Conservation, Government of Vanuatu, (2018) <i>National Biodiversity Strategy and Action Plan 2018–2030 (2018–2023 edition)</i> , Port Vila, Vanuatu.

13	Department of Environmental Protection and Conservation, Government of the Republic of Vanuatu, <i>National Invasive Species Strategy and Action Plan 2014-2020</i> .
14	East Asian Seas (EAS) Congress (2021) 'Charting a New Decade of H.O.P.E (Healthy Ocean, People, and Economies);Collab 3 – Regional Seminar on Biofouling Management and Invasive Aquatic Species', Online.
15	Environmental Protection Agency (EPA), Guyana (2011) <i>Biodiversity Enabling Activity Project (BEAP). Assessment of Capacity Building Needs: Invasive Alien Species in Guyana. National Strategy and Action Plan</i> , Georgetown, Guyana.
16	Faahi Gahua Takatakaimotu (2024) <i>Niue National Invasive Species Strategy and Action Plan 2021–2029</i> , Department of Environment, NIUE. Secretariat of the Pacific Regional Environment Programme (SPREP), Apia, Samoa.
17	Factuar D (2021) <i>A Rapid Assessment Study on Biofouling Management and Invasive Aquatic Species in the East Asian Seas Region</i> .
18	Federated States of Micronesia (2018) <i>National Biodiversity Strategy and Action Plan 2018–2023</i> .
19	Government of Antigua and Barbuda (2014) <i>THE ANTIGUA AND BARBUDA MERCHANT SHIPPING (AMENDMENT) ACT, 2014. No.15 of 2014</i> . Ralph George, Government Printer., Government Printing Office, Antigua and Barbuda.
20	Government of Antigua and Barbuda. Department of Environment (2023a) <i>Critical Situation Analysis. Invasive Alien Species Profiles.</i> , Department of Environment, St. John’s, Antigua.
21	Government of Antigua and Barbuda. Department of Environment (2023b) <i>National IAS Strategy and Action Plan</i> , Department of Environment, St. John’s Antigua.
22	DEPARTMENT OF MARINE SERVICES AND MERCHANT SHIPPING (ADOMS) (2018) <i>Information Notice 2018-006. Control and Management of Ship Biofouling</i> .
23	Government of Cabo Verde <i>Sixth National Report for the Convention on Biological Diversity</i> , Cabo Verde.
24	Government of Fiji (2014) <i>Marine (Anti-fouling Systems on Ships) Regulations 2014. LEGAL NOTICE NO. 106. MARITIME TRANSPORT DECREE 2013. (DECREE NO. 20 OF 2013)</i> .
25	Government of Kiribati (2015) <i>Kiribati National Invasive Species Strategy and Action Plan 2015-2020</i> .
26	Government of Maldives 'Sixth National Report for the Convention on Biological Diversity'.
27	Government of Mauritius (2011) <i>Sixth National Report for the Convention on Biological Diversity</i> .
28	Government of Papua New Guinea (2014) <i>Marine Pollution (Ships and Installations) Act 2013</i> .
29	Government of Samoa (2008) <i>MARINE POLLUTION PREVENTION ACT 2008</i> .
30	Government of Singapore (2010) <i>PREVENTION OF POLLUTION OF THE SEA (HARMFUL ANTI-FOULING SYSTEMS) REGULATIONS 2010. No. S 198. PREVENTION OF POLLUTION OF THE SEA ACT (CHAPTER 243)</i> .
31	Government of Solomon Islands (2011) <i>SHIPPING (MARINE POLLUTION) REGULATIONS 2011. SHIPPING ACT 1998 (No 5 of 1998). Legal Notice No. 67</i> .

32	Government of Tuvalu (2022a) <i>MARINE POLLUTION ACT. 2022 Revised Edition. CAP. 48.16.</i>
33	Government of Tuvalu (2022b) <i>MERCHANT SHIPPING ACT. 2022 Revised Edition. CAP. 48.28.</i>
34	Gruber M, Pierce R and Kanako K (2023) <i>Republic of the Marshall Islands National Invasive Species Strategy and Action Plan 2021–2029</i> , Secretariat of the Pacific Regional Environment Programme (SPREP), Apia, Samoa.
35	International Merchant Marine Registry of Belize (IMMARBE) (2008) <i>Merchant Shipping Notice MSN-0034. ENTRY INTO FORCE OF THE AFS-CONVENTION. INTL. CONVENTION ON THE CONTROL OF HARMFUL ANTI-FOULING SYSTEMS.</i>
36	International Merchant Marine Registry of Belize (IMMARBE) (2017) <i>Merchant Marine Notice-MM-17-006 List of Certificates and Documents required to be Carried Onboard Ships, 2017 (Superseded MSN-0026).</i>
37	John L and Radford E (2016) <i>Progress towards a Strategy for Invasive Alien Species management in the Caribbean UKOTs</i> , doi:10.13140/RG.2.2.17800.96005.
38	Joint Nature Conservation Committee (JNCC) (2014) <i>Fifth National Report to the United Nations Convention on Biological Diversity: United Kingdom.</i>
39	Key J (2017) <i>Tackling Invasive Non-Native Species in the UK Overseas Territories. Gap Analysis of Biosecurity Capacity.</i>
40	Mahot (2014) <i>National Biodiversity Strategy and Action Plan 2015–2030</i> , Directorate General for the Environment (DGA), Praia, Cabo Verde.
41	MARITIME AND PORT AUTHORITY OF SINGAPORE (2022) <i>PREVENTION OF POLLUTION OF THE SEA (HARMFUL ANTI-FOULING SYSTEMS) (AMENDMENT) REGULATIONS 2022. SHIPPING CIRCULAR NO. 19 OF 2022.</i>
42	Ministry of Agriculture, Fisheries, and Environment, Union of Comoros. (2016) <i>Updated National Biodiversity Strategy and Action Plan.</i>
43	Ministry of Agriculture, Fisheries, and Environment, Union of Comoros. (2019) <i>Sixth National Biodiversity Report of the Union of Comoros.</i>
44	Ministry of Agriculture, Forestry, Fisheries, the Environment and Sustainable Development, Belize Forest Department, (2016) <i>National Biodiversity Strategy and Action Plan (2016–2020)</i> , Belize, Belmopan, Belize.
45	Ministry of Ecology, France (2014) <i>Fifth National Report of France to the Convention on Biological Diversity.</i>
46	Ministry of Economic Affairs, Kingdom of the Netherlands <i>Convention on Biological Diversity: Fifth National Report of the Kingdom of the Netherlands.</i>
47	Ministry of Environment, Climate Change, Disaster Management & Meteorology (2016) <i>National Biodiversity Strategic Action Plan 2016–2020: Building a unified, vibrant and informed Solomon Islands</i> , Government of the Solomon Islands, Honiara, Solomon Islands.
48	Ministry of Environment, Natural Resources, Physical Planning and Fisheries, Dominica. (2013) <i>Dominica National Biodiversity Strategy and Action Plan 2014–2020.</i>

49	Ministry of Environment and Energy (2015) <i>Maldives National Biodiversity Strategy and Action Plan 2016–2025</i> , Ministry of Environment and Energy, Maldives.
50	Ministry of Lands, Environment, Climate Change and Natural Resources, (2013) <i>National Invasive Species Strategy and Action Plan 2013-2020</i> , Government of the Kingdom of Tonga, Nuku'alofa, Tonga.
51	Ministry of Marine Resources, Cook Islands and Pacific Community (SPC) (2018) <i>National Strategy on Aquatic Biosecurity for the Cook Islands</i> , Noumea, New Caledonia.
52	Ministry of Public Housing, Spatial Planning, Environment and Infrastructure <i>Nature Policy Plan 2021–2025</i> .
53	Moultrie S (2013) <i>The Bahamas national invasive species strategy 2013</i> , Nassau, The Bahamas.
54	National Biodiversity Working Group, Democratic Republic of Timor-Leste, (2015) <i>The National Biodiversity Strategy and Action Plan of Timor-Leste (2011–2020) – Revised edition</i> , Ministry of Economy and Development.
55	National Environmental Protection Council, Republic of Palau (2004) <i>Palau National Invasive Species Strategy</i> , Koror, Palau.
56	National Parks Board <i>Singapore Thematic Report on Alien and Invasive Species</i> .
57	NAURU SHIP REGISTRY (2024) <i>Non-Convention Regulations for Vessels of more than 12 metres in length</i> .
58	O'Brien CE, Johnston MW and Kerstetter DW (2017) 'Ports and pests: Assessing the threat of aquatic invasive species introduced by maritime shipping activity in Cuba', <i>Mar Pollut Bull</i> , 125(1-2):92-102, doi:10.1016/j.marpolbul.2017.07.071.
59	Office of the Maritime Administrator, Commonwealth of Dominica, <i>Marine Safety Circular CD-MS-C 06-06 Rev01: Anti-fouling systems on ships</i> .
60	Onorio K and Deiye T <i>Nauru's Biodiversity Strategy and Action Plan. Final draft</i> , National Environmental Coordinating Committee (NECC), Department of Commerce, Industries and Environment, Government of the Republic of Nauru, Nauru.
61	Palau Conservation Society PaPD (2016) <i>Revised National Biodiversity Strategy and Action Plan 2015–2025: Promoting wise development to achieve conservation and sustainable use of biodiversity</i> , Ministry of Natural Resources, Environment and Tourism, Republic of Palau, Koror, Palau.
62	Palau International Ship Registry (2018) <i>CONTROL OF HARMFUL ANTI-FOULING SYSTEMS ON SHIPS. Marine Notice 135.1. V. 1.0 Rev. 10/2018</i> .
63	Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) (2022) <i>SECOND REGIONAL TASK FORCE MEETING ON BIOFOULING MANAGEMENT AND INVASIVE AQUATIC SPECIES. MEETING REPORT</i> , New Coast Hotel, Manila, Philippines.
64	'Preventing the Costs of Invasive Alien Species in Barbados and the OECS: Successes, lessons learnt, and strategic partnerships in conserving biodiversity' (20–22 March 2024) [conference presentation], <i>REGIONAL WORKSHOP</i> , Marriott Hotel, Frigate Bay, St. Kitts and Nevis.

65	Reaser JK (2013) <i>National Invasive Alien Species Strategy & Action Plan (NIASSAP) 2014–2020</i> , National Environment and Planning Agency (NEPA), Jamaica, Kingston, Jamaica.
66	Republic of Cuba (2019) <i>Sixth National Report to the Convention on Biological Diversity</i> , Ministry of Science, Technology, and Environment.
67	Republic of Kiribati (2019) <i>Maritime (Amendment) Act 2019</i> .
68	REPUBLIC OF NAURU (2018) <i>Shipping (Registration of Foreign Vessels) Act 2018 (No. 2 of 2018)</i> .
69	Republic of Palau <i>Maritime Regulations</i> .
70	Republic of Suriname (2019) <i>The Sixth National Report to the United Nations Convention on Biological Diversity</i> .
71	Secretariat of the Pacific Regional Environment Programme (SPREP) (2023) <i>Tuvalu National Invasive Species Strategy and Action Plan 2022–2027</i> , Apia, Samoa.
72	Shipping Division, Ministry of Public Infrastructure, National Development Unit, Land Transport and Shipping. (2012) <i>Report of the Working Group on Development of Guidelines and Recommendations for In-water Hull Cleaning Operations in Designated Port Areas</i> .
73	Smith NS, Gray AR, Hollarsmith J and Côté IM (2021) <i>Preventing the costs of invasive alien species (IAS) in Barbados and the OECS countries</i> , Technical Report, GEFSEC ID 9408, GEF, UNEP, CABI.
74	Smith SR, van der Burg WJ, Debrot AO, van Buurt G and de Freitas JA (2014) <i>Key elements towards a joint invasive alien species strategy for the Dutch Caribbean</i> , C020/14; PRI Report 550, The Hague, The Netherlands.
75	The Bahamas Maritime Authority (2021) <i>The Bahamas National Requirements. Version 10.2</i> .
76	The Bahamas Maritime Authority (2024) <i>Information Notice 08. Version No. 2.2. Control and Management of Ships' Biofouling</i> .
77	The Department of Marine and Wildlife Resources (2017) <i>AMERICAN SAMOA INVASIVE SPECIES STRATEGY AND ACTION PLAN</i> , American Samoa.
78	The Government of Seychelles (2011a) <i>Biosecurity Operational Manual. Version 4.0</i> , Ministry of Investment, Natural Resources and Industry and the Department of Natural Resources (Seychelles Agricultural Agency).
79	The Government of Seychelles (2011b) <i>Draft ANIMAL AND PLANT BIOSECURITY BILL, 2011</i> .
80	Tuvalu Ship Registry (2015) <i>ANTI-FOULING SYSTEMS CONVENTION. MARINE CIRCULAR MC-3/2008/1</i> .
81	Tuvalu Ship Registry (2021) <i>TUVALU YACHT CODE FOR PRIVATE AND COMMERCIAL YACHTS. Edition 2021-Rev 1</i> .
82	Tuvalu Ship Registry (2024) <i>Non-Convention regulations for vessels of more than 12 metres in length</i> .
83	UICN Comité français (2019) <i>Espèces exotiques envahissantes marines : risques et défis pour les écosystèmes marins et littoraux des collectivités françaises d'outre-mer. État des lieux et recommandations</i> , Paris, France.

84	United Nations Environment Programme (UNEP) and CAB International (CABI) (2014) 'PROGRAMME & ABSTRACTS' [conference presentation], <i>Policies, Strategies and Best Practices for Managing Invasive Alien Species (IAS) in the Insular Caribbean. March 31st – April 4th 2014</i> , Radisson Trinidad, Port of Spain, Trinidad & Tobago.
85	Zahir M, Mohamed M, Atho Mohamed I, Shaheem FA, Simah M, Niyaz AA, Nidham H, Abdul Rasheed M, Huma A, Hameed AM, Abdul Rasheed M, Anwar A, Furaz M, Ajmal I and Aflah M (2015) <i>Invasive Alien Species. PEMPHIS Environmental Newsletter</i> , Ministry of Environment and Energy.
86	Rhon A. Connor (2008) <i>Anquilla Invasive Species strategy (2008) draft</i> .
87	Muscetta G, Shine C and Ziller SR (2011) <i>Invasive Alien Species in Guyana: Assessment Report, National Strategy and Action Plan</i> , Georgetown, Guyana.

Box 12: Proposed characteristics that contribute to resilience	
Aware	Understand the operational context of the biosecurity system and use this to identify, assess and prioritise current and emerging risks on an ongoing basis.
Prepared	Have the appropriate plans, tools, agreements and arrangements in place to support biosecurity risk management in normal and emergency circumstances, including the capacity to detect pest and disease incursions through targeted and general surveillance activities.
Resourced	Have sufficient capability, including financial, physical and human resources, as well as organisational capability, to support biosecurity risk management in normal circumstances, as well as surge capacity to address emergency situations.
Responsive	Have the capacity to respond in a timely and effective manner to incursions of unwanted pests and diseases to increase the likelihood of eradication or containment; be able to deal with anomalous situations and disruptions to normal activities without cascading consequences.
Adaptive	have the capacity to recover from or adapt to new circumstances that arise after a pest or disease incursion, including adaptation by producers, industries and communities, including by taking new actions and modifying behaviours, or applying existing resources to new roles; using monitoring and evaluation processes to identify system performance issues and ways to address them.

Figure D1 *Proposed five characteristics that contribute to resilience in national biosecurity system by Schneider, Karen et al. (2020).*

Appendix E

Associated to Chapter 5 “Strengthening the capacity of Small Island Developing States to monitor ship biofouling: insights from Australia”.

Table E1 Resources on Australia’s Biosecurity System.

Biosecurity Component	Biosecurity Measures	Output	Source
Legislative Layer	Biosecurity Act 2015	Compliance and sanctions	https://www.legislation.gov.au/C2015A00061/latest/versions
	Biosecurity Regulation 2016		https://www.legislation.gov.au/F2016L00756
	NW Fisheries Management Act 1994		https://legislation.nsw.gov.au/view/whole/pdf/inforce/2025-10-04/act-1994-038
	NSW Biosecurity Regulation 2017		https://legislation.nsw.gov.au/view/whole/pdf/inforce/2025-10-04/sl-2017-0232
	NSW Biosecurity Act 2015		https://legislation.nsw.gov.au/view/whole/pdf/inforce/2025-10-04/act-2015-024
	NT FISHERIES REGULATIONS 1992		https://legislation.nt.gov.au/Legislation/FISHERIES-REGULATIONS-1992
	QLD Biosecurity Act 2014		https://www.legislation.qld.gov.au/view/pdf/inforce/current/act-2014-007

QLD Biosecurity Regulation 2016	https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2016-0075
SA Fisheries Management Act 2007	https://www.legislation.sa.gov.au/legislation/lz/v/a/2007/fisheries%20management%20act%202007_4/2007.4.un.pdf
SA Environment Protection Act 1993	https://www.legislation.sa.gov.au/legislation/lz/c/a/environment%20protection%20act%201993/current/1993.76.auth.pdf
TAS BIOSECURITY ACT 2019	https://www.legislation.tas.gov.au/view/html/asmade/act-2019-022
TAS Biosecurity Regulations 2022	https://www.legislation.tas.gov.au/view/html/asmade/sr-2022-083
VIC Fisheries Act 1995 (Noxious Aquatic Species provisions under section 75 of the Act)	https://content.legislation.vic.gov.au/sites/default/files/2025-03/95-92aa103-authorized.pdf
WA Fish Resources Management Act 1994 (FRMA)	https://www.legislation.wa.gov.au/legislation/statutes.nsf/law_a283.html
WA Fish Resources Management Regulations 1995 (FRMR)	https://www.legislation.wa.gov.au/legislation/statutes.nsf/law_s4447.html
WA Biosecurity and Agriculture Management Act 2007 (BAM Act).	https://www.legislation.wa.gov.au/legislation/statutes.nsf/law_a146629.html
WA Environmental Protection Act 1986	https://www.legislation.wa.gov.au/legislation/statutes.nsf/law_a252.html

Policy & Governance Layer	DAFF's Compliance Policy	Principles, approaches, and guidance for applying the law	https://www.agriculture.gov.au/sites/default/files/documents/compliance_policy.pdf
	National Marine Pest Surveillance Strategy		https://www.marinepests.gov.au/sites/default/files/Documents/national-marine-pest-surveillance-strategy_0.pdf
	National Marine Pest Surveillance Work Plan		https://www.marinepests.gov.au/sites/default/files/Documents/national-marine-pest-surveillance-work-plan.pdf
	National marine pest stakeholder engagement strategy		https://www.marinepests.gov.au/sites/default/files/Documents/national_marine_pest_stakeholder_engagement_strategy.pdf
	National Biosecurity Strategy 2022-2032		https://www.biosecurity.gov.au/about/national-biosecurity-committee/nbs
	National Biosecurity Strategy implementation plan		https://www.biosecurity.gov.au/sites/default/files/2024-02/national-biosecurity-strategy-implementation-plan.pdf
	National Biosecurity Strategy action plan		https://www.biosecurity.gov.au/sites/default/files/2024-12/national-biosecurity-strategy-national-action-plan.pdf
	National Environmental Biosecurity Response Agreement		https://www.agriculture.gov.au/sites/default/files/documents/nebra.pdf
	NSW Invasive Species Plan 2023-2028		https://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/1629051/18235

		-NSW-Invasive-Species-Plan-2023-2028-v2-FINAL.pdf
	NT biosecurity strategy 2016-2026	https://daf.nt.gov.au/media/docs/agribusiness/agricultural-developments/nt-biosecurity-strategy.pdf
	Queensland Biosecurity Strategy 2024-2029	https://www.publications.qld.gov.au/dataset/queensland-biosecurity-strategy/resource/e3869c8e-55b6-4578-95f2-43b4dbaeeb97
	Tasmanian Biosecurity Strategy 2023-2027	https://nre.tas.gov.au/biosecurity-tasmania/biosecurity-policy-strategy-publications/tasmanian-biosecurity-strategy-2023-2027
	Tasmanian Biosecurity Policy	https://nre.tas.gov.au/Documents/Tasmanian%20Biosecurity%20Policy.pdf
	Code of practice for vessel and facility management (marine and inland waters) (SA)	https://www.epa.sa.gov.au/files/47792_vessels.pdf
	In-water Biofouling Cleaning Policy for Vessels arriving from Interstate or Overseas (TAS)	https://nre.tas.gov.au/Documents/In-water%20Biofouling%20Cleaning%20Policy%20for%20Vessels%20arriving%20from%20Interstate%20or%20Overseas.pdf
	HARBOUR MASTERS DIRECTIONS Sydney Harbour and Port Botany (in water cleaning) (NSW)	https://www.portauthoritynsw.com.au/sites/default/files/media/migrated/files/harbour-masters-directions-2024-in-force-june-2024.pdf

PRE-BORDER (Operational Layer)	Temporal Development of Biofouling Assemblages	Pest Risk Analysis - geographical location of ports and residency time of vessels at those ports	https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/temporal-development-biofouling-assemblages.pdf
	Assessment of reproductive propagule size for biofouling risk groups	Pest Risk Analysis - risk associated with organisms release during in-water cleaning and determination of acceptable filtration levels.	https://www.agriculture.gov.au/sites/default/files/documents/assessment-of-reproductive-propagule-size-for-biofouling-risk-groups.pdf
	Chemical contaminant risks associated with in-water cleaning of vessels	Pollution Risk Analysis- In-water cleaning risks management	https://www.agriculture.gov.au/sites/default/files/documents/chemical-contaminant-risks-associated-with-iwc-of-vessels.pdf
	MAMPEC modelling of key Australian ports to predict environmental impacts of in-water cleaning discharge	Pollution Risk Analysis - Predicts chemical concentrations that may be released during in-water cleaning	https://cebra.unimelb.edu.au/data/assets/pdf_file/0009/3457134/in-water-cleaning-final-V3.pdf
	Recreational boat operators' self-management of biofouling in Australia	Identifying communication strategies to support pathway risk management.	https://daff.ent.sirsidynix.net.au/client/en_AU/search/asset/1027096/0
	Species biofouling risk assessment	Pest Risk Analysis - assessment of biosecurity risk from marine pest introduction, establishment, and spread via biofouling	https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/animal-plant/pests-diseases/marine-pests/biofouling-consult/species-biofouling-risk-assessment.pdf
	Factors that influence vessel biofouling and its prevention and management	Biofouling risk profiling - evaluation of factors contributing to vessel biofouling and their relation to biosecurity risk	https://cebra.unimelb.edu.au/data/assets/pdf_file/0010/3822922/Endorsed-CEBRA-190803-Final-Report.pdf
	The Maritime and Aircraft Reporting System (MARS) and the Vessel Compliance Scheme (VCS)	Mandatory PAR - Pest Risk Analysis	https://www.agriculture.gov.au/biosecurity-trade/aircraft-vessels-military/vessels/mars

Australian biofouling management requirements Version 2	Mandatory PAR - Pest Risk Analysis	https://www.agriculture.gov.au/sites/default/files/documents/Australian-biofouling-management-requirements.pdf
Recreational boat operators' self-management of biofouling in Australia	Identifying communication strategies to support pathway risk management.	https://daff.ent.sirsidynix.net.au/client/en_AU/search/asset/1027096/0
Factors that influence vessel biofouling and its prevention and management	Biofouling risk profiling - evaluation of factors contributing to vessel biofouling and their relation to biosecurity risk	https://cebra.unimelb.edu.au/_data/assets/pdf_file/0010/3822922/Endorsed-CEBRA-190803-Final-Report.pdf
The Maritime and Aircraft Reporting System (MARS) and the Vessel Compliance Scheme (VCS)	Mandatory PAR - Pest Risk Analysis	https://www.agriculture.gov.au/biosecurity-trade/aircraft-vessels-military/vessels/mars
Australian biofouling management requirements Version 2	In-Water Cleaning Standards - Preventing biosecurity and chemical contamination risks	https://www.agriculture.gov.au/sites/default/files/documents/Australian-biofouling-management-requirements.pdf
Australian anti-fouling and in-water cleaning guidelines Exposure draft	These guidelines outline Australia's in-water cleaning standards and provide a voluntary framework to help regulators assess biosecurity and chemical contamination risks from cleaning vessel biofouling in Australian waters.	https://www.agriculture.gov.au/sites/default/files/documents/exposure-draft-australian-anti-fouling-and-iwc-guidelines.pdf
Antifouling performance standards for the Maritime industry (2007)	Antifouling Efficiency / Performance Analysis - Preventing biosecurity risks	https://www.dcceew.gov.au/sites/default/files/documents/antifouling-framework.pdf

National biofouling management guidelines for recreational vessels	Reducing the risk of spreading marine pests through good maintenance and having effective antifouling.	https://www.marinepests.gov.au/sites/default/files/Documents/recreational-vessel-biofouling-guidelines.pdf
National biofouling management guidelines for commercial vessels	Preventing the introduction of marine pests and protect the marine environment	https://www.marinepests.gov.au/sites/default/files/Documents/commercial-vessels-biofouling-guidelines.pdf
National biofouling management guidelines for commercial fishing vessels	Preventing the introduction of marine pests and protect the marine environment	https://www.marinepests.gov.au/sites/default/files/Documents/commercial-fishing-vessel-biofouling-guidelines.pdf
National biofouling management guidelines for non-trading vessels	Reducing and managing the risk of marine pest introduction, establishment and spread through regular maintenance of vessels following an assessment of biofouling risks of the specific vessel types. Detailed records of all biofouling mitigation, maintenance and repair activities carried out on the vessel should be maintained.	https://www.marinepests.gov.au/sites/default/files/Documents/non-trading-vessel-biofouling-guidelines.pdf
National biofouling management guidelines for marinas, slipways, boat maintenance and recreational boating facilities	Reducing and managing the risk of marine pest introduction, establishment and spread through awareness, environmental management plan/code of practice/biosecurity plan, infrastructure management, ensuring compliance with vessel cleaning and	https://www.marinepests.gov.au/sites/default/files/Documents/National%20biofouling%20management%20guidelines%20for%20marinas%2C%20slipways%2C%20boat%20maintenance%20and%20recreational%20boating%20facilities.pdf

		maintenance, surveillance and reporting	
National biofouling management guidelines for the aquaculture industry	Reducing the risk of marine pest infestations and spread	https://www.marinepests.gov.au/sites/default/files/Documents/aquaculture-biofouling-guidelines.pdf	
National biofouling management guidelines for the petroleum production and exploration industry	Reducing and managing the risk of marine pest introduction, establishment and spread through regular maintenance of vessels, equipment and infrastructure following an assessment of biofouling risks. Vessel operators should maintain a biofouling record book for each vessel. The book should record details of all inspections and biofouling management measures undertaken on that vessel.	https://www.marinepests.gov.au/sites/default/files/Documents/petroleum-exploration-biofouling-guidelines.pdf	
MarinePestPlan 2018–2023	Sets strategic priorities to strengthen national readiness and prevention capabilities for marine pest biosecurity.	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pest-plan-2018-2023.pdf	
National priorities for introduced marine pest research and development 2013-2023	This document guides marine pest R&D to support timely, evidence-based decision-making, placing it within Anticipate and Prepare.	https://www.marinepests.gov.au/sites/default/files/Documents/national-priorities-marine-pest-research-2013-2023.pdf	
Review of biosecurity and contaminant risks associated with in-water cleaning	This review informs risk-based decision-making for in-water hull cleaning and educates stakeholders on best practices and regulations.	https://www.marinepests.gov.au/sites/default/files/Documents/review-biosecurity-contaminant-risks-in-water-cleaning.pdf	

Appraising the delivery of communications about marine pests to the commercial fishing industry	This document guides stakeholders on safe in-water cleaning, promoting awareness and risk-based biofouling management.	https://www.marinepests.gov.au/sites/default/files/Documents/biofouling-strategies-commercial-fishing.pdf
The relative contribution of vectors to the introduction and translocation of invasive marine species	This project evaluates the contributions of marine pest vectors in Australia and globally to inform management and research priorities.	https://www.marinepests.gov.au/sites/default/files/Documents/relative-contribution-vectors-introduction-translocation-invasive-marine-species.pdf
Project summary – Passive surveillance, education, and awareness of marine pests	This project reviewed existing marine pest awareness materials, identified key observer groups, and highlighted sectors needing targeted education.	https://www.marinepests.gov.au/sites/default/files/Documents/Project%20summary%20-%20Passive%20surveillance%2C%20education%2C%20and%20awareness%20of%20marine%20pests.pdf
Partnerships	List of industry and government to prevent, detect and control marine pest threats	https://www.marinepests.gov.au/what-we-do/partnerships
Australian territory biosecurity requirements for non-commercial vessels V2	Visual guide that outlines the biosecurity control steps you will go through	https://www.agriculture.gov.au/sites/default/files/documents/vis-diagram-biosec-requirements-non-comm-vessels.pdf
Vessels entering WA waters (Biofouling Management)	Guidelines	https://www.dpird.wa.gov.au/business/biosecurity/aquatic-biosecurity/vessels-entering-wa-waters/?accordion=accordiona198c954589f484888717614e4de73f
Managing biofouling (VIC)	Guidelines	https://agriculture.vic.gov.au/biosecurity/marine-pests/managing-biofouling

	Invasive Marine Pest Module under the Invasive Plants and Animals Policy Framework (VIC)	This document guides the development of regional and place-specific strategies for managing invasive marine pests.	https://agriculture.vic.gov.au/biosecurity/protecting-victoria/legislation-policy-and-permits/invasive-plants-and-animals-policy-framework/Invasive-Marine-Pests-Module-.pdf
	South Australian in-water cleaning guidelines	In-water cleaning guidelines for South Australia	https://pir.sa.gov.au/_data/assets/pdf_file/0004/472981/SA_in-water_cleaning_guidelines.pdf
	Cleaning marine equipment factsheet (SA)	Factsheet on cleaning marine equipment in South Australia	https://pir.sa.gov.au/_data/assets/pdf_file/0008/335969/Cleaning_marine_equipment_factsheet_-_20_October_2018.pdf
	Checklist-for-Boaters,-Fishers-and-Divers-Travelling-to-Tasmania	Declaration for Boaters, Fishers, Divers and Recreational Aquatic Equipment Users Travelling to Tasmania	https://nre.tas.gov.au/Documents/Checklist-for-Boaters,-Fishers-and-Divers-Travelling-to-Tasmania.pdf
	Marine pest advisory booklet for boaters and fishers (NSW)	Booklet on how to keep boats and fishing gears clean	https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/637590/marine-pests-booklet.pdf
	Biofouling Primefact (Biofouling on recreational vessels)	Biofouling on recreational vessels	https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0011/1395632/Primefact-Biofouling-on-recreational-vessels.pdf
BORDER (Operational Layer)	Australian biofouling management requirements Version 2	Mandatory PAR - Pest Risk Analysis	https://www.agriculture.gov.au/sites/default/files/documents/Australian-biofouling-management-requirements.pdf
	Invasive marine species (IMS) inspections of vessels (WA)	Vessel Inspection	https://www.dpird.wa.gov.au/business/biosecurity/aquatic-

			biosecurity/vessels-entering-wa-waters/biofouling-inspectors/
	Invasive Marine Pest Expert Guidance Statement (WA)	This document sets out the criteria for approving qualified marine pest experts to conduct vessel inspections and ensure appropriate risk management.	https://www.dpird.wa.gov.au/global/assets/invasive_marine_pest_expert_guidance_statement.pdf
	IMS Inspection Report Reqs Guidance Statement (WA)	This document provides guidance on the content and structure of invasive marine species (IMS) inspection reports.	https://www.dpird.wa.gov.au/global/assets/ims_inspection_report_reqs_guidance_statement.pdf
	Best Practice IMS Inspections Guidance Statement (WA)	This document provides guidance on conducting invasive marine species (IMS) inspections according to industry best practice.	https://www.dpird.wa.gov.au/global/assets/best_practice_ims_inspections_guidance_statement.pdf
	Hull pest inspections for visiting boats (NT)	Vessel Inspection	https://nt.gov.au/marine/for-all-harbour-and-boat-users/biosecurity/hull-pest-inspections-for-visiting-boats
	Vessel In-water Biofouling Cleaning Factsheet (TAS)	Factsheet on in-water cleaning in Tasmania	https://nre.tas.gov.au/Documents/Vessel%20In-water%20Biofouling%20Cleaning%20Factsheet.pdf
	Biofouling Primefact (Biofouling on recreational vessels)(NSW)	Biofouling on recreational vessels	https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0011/1395632/Primefact-Biofouling-on-recreational-vessels.pdf
POST-BORDER (Operational Layer)	National Marine Pest Surveillance Work Plan		https://www.marinepests.gov.au/sites/default/files/Documents/national-

		marine-pest-surveillance-work-plan.pdf
The Australian Priority Marine Pest List		https://www.marinepests.gov.au/what-we-do/apmpl
Australian Priority Marine Pests List: Process and Outcomes		https://www.marinepests.gov.au/sites/default/files/Documents/apmpl-process-outcomes.pdf
Australian marine pest monitoring manual		https://www.marinepests.gov.au/sites/default/files/Documents/australian-marine-pest-monitoring-manual.pdf
Australian marine pest monitoring guidelines		https://www.marinepests.gov.au/sites/default/files/Documents/australian-marine-pest-monitoring-guidelines.pdf
marine-pest-molecular-studies-relevant-australia		https://www.marinepests.gov.au/sites/default/files/Documents/marine-pest-molecular-studies-relevant-australia.xlsx
Guidelines for development and validation of assays for marine pests		https://www.marinepests.gov.au/sites/default/files/Documents/guideline-development-validation-assays-marine-pests.pdf
eDNA project summary		https://www.marinepests.gov.au/sites/default/files/Documents/project-summary-edna-sampling-biophysical-modelling-marine%20pests.pdf
Review and Enhancement of Remotely Operated Vehicles for Marine Pest Surveillance document		https://www.marinepests.gov.au/what-we-do/surveillance/review-enhancement-rov-mp-surveillance

List of priority marine pest species for surveillance - March 2024		https://www.marinepests.gov.au/sites/default/files/Documents/List%20of%20priority%20marine%20pest%20species%20for%20surveillance%20-%20March%202024.xlsx
National Biosecurity Strategy 2022–2032		https://www.biosecurity.gov.au/about/national-biosecurity-committee/nbs
National Biosecurity Strategy Implementation Plan		https://www.biosecurity.gov.au/sites/default/files/2024-02/national-biosecurity-strategy-implementation-plan.pdf
National Biosecurity Strategy Action Plan 2024		https://www.biosecurity.gov.au/sites/default/files/2024-12/national-biosecurity-strategy-national-action-plan.pdf
Biosecurity incident management system: marine pest version		https://www.marinepests.gov.au/sites/default/files/Documents/biosecurity-emergency-management-bimg_0.pdf
Emergency Marine Pest Plan		https://www.marinepests.gov.au/what-we-do/emergency/emergency-marine-pest-plan#:~:text=Four%20marine%20pest%20response%20manuals%20provide%20guidance%20on,a%20specific%20marine%20pest%20manual%20does%20not%20exist.
Marine pest response manual - EMPPlan		https://www.marinepests.gov.au/sites/default/files/Documents/Marine%20

		0pest%20response%20manual%20%E2%80%93%20EMPPlan.pdf
Response manual for invasive marine bivalves		https://www.marinepests.gov.au/sites/default/files/Documents/response-manual-invasive-marine-bivalves-empplan.pdf
Response manual for invasive marine crabs		https://www.marinepests.gov.au/sites/default/files/Documents/response-manual-invasive-marine-crabs-EMPPlan.pdf
Response manual for Asian kelp (<i>Undaria pinnatifida</i>)		https://www.marinepests.gov.au/sites/default/files/Documents/empplan-rapid-response-manual-undaria-pinnatifida_0.pdf
Response manual for northern Pacific seastar (<i>Asterias amurens</i>)		https://www.marinepests.gov.au/sites/default/files/Documents/empplan-rapid-response-manual-asterias-amurensis_0.pdf
National control plan for the Northern Pacific seastar		https://www.marinepests.gov.au/sites/default/files/Documents/national-control-plan-northern-pacific-seastar-asterias-amurensis.pdf
National control plan for the Asian bag or date mussel		https://www.marinepests.gov.au/sites/default/files/Documents/national-control-plan-asian-bag-date-mussel-musculista-senhousia.pdf
National control plan for the European green shore crab		https://www.marinepests.gov.au/sites/default/files/Documents/national-control-plan-european-green-shore-crab-carcinus-maenas.pdf

National control plan for the Japanese seaweed or wakame		https://www.marinepests.gov.au/sites/default/files/Documents/national-control-plan-japanese-seaweed-wakame-undaria-pinnatifida.pdf
National control plan for the European or basket shell clam		https://www.marinepests.gov.au/sites/default/files/Documents/national-control-plan-european-basket-shell-clam-varicorbula-gibba.pdf
National control plan for the European fan worm		https://www.marinepests.gov.au/sites/default/files/Documents/national-control-plan-european-fan-worm-sabella-spallanzanii.pdf
Marine pest deck: Invasive species guide (VIC)		https://agriculture.vic.gov.au/biosecurity/marine-pests/marine-pest-deck-invasive-species-guide/Marine-Pest-Deck-2022-.pdf
Victorian Port Surveillance Program		https://agriculture.vic.gov.au/biosecurity/marine-pests/victorian-port-surveillance-program
Marine pest field guide (NT)		https://nt.gov.au/media/docs/boating,-fishing-and-marine/boating_and_marine/marine-pest-field-guide.pdf
Queensland marine pest and disease guide		https://www.daf.qld.gov.au/contact/report-a-biosecurity-pest-or-disease?form=marine_pests-1554278
Report a biosecurity pest or disease - online form (QLD)		https://www.daf.qld.gov.au/contact/report-a-biosecurity-pest-or-

			disease?form=marine_pests-1554278
	Biofouling Primefact (Biofouling on recreational vessels)	Biofouling on recreational vessels	https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0011/1395632/Primefact-Biofouling-on-recreational-vessels.pdf
	Make 'Clean' Part of your routine (clean aquatic gear & equipment) (NSW)	Cleaning aquatic gear and equipment	https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/637585/PUB13-25-Primefact-1290-Make-clean-part-of-your-routine.pdf
	Notifiable marine pests in NSW	Reporting a marine pest	https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/1302991/PUB21-3-Primefact-Notifiable-aquatic-marine-pests-in-NSW.pdf
Education and awareness of marine pests	National priorities for introduced marine pest research and development 2013-2023	This document guides marine pest R&D to support timely, evidence-based decision-making, placing it within Anticipate and Prepare.	https://www.marinepests.gov.au/sites/default/files/Documents/national-priorities-marine-pest-research-2013-2023.pdf
	Review of biosecurity and contaminant risks associated with in-water cleaning	This review informs risk-based decision-making for in-water hull cleaning and educates stakeholders on best practices and regulations.	https://www.marinepests.gov.au/sites/default/files/Documents/review-biosecurity-contaminant-risks-in-water-cleaning.pdf
	Appraising the delivery of communications about marine pests to the commercial fishing industry	This document guides stakeholders on safe in-water cleaning, promoting awareness and risk-based biofouling management.	https://www.marinepests.gov.au/sites/default/files/Documents/biofouling-strategies-commercial-fishing.pdf
	The relative contribution of vectors to the introduction and translocation of invasive marine species	This project evaluates the contributions of marine pest vectors in Australia and globally to inform management and research priorities.	https://www.marinepests.gov.au/sites/default/files/Documents/relative-contribution-vectors-introduction-

		translocation-invasive-marine-species.pdf
Project summary – Passive surveillance, education, and awareness of marine pests	This project reviewed existing marine pest awareness materials, identified key observer groups, and highlighted sectors needing targeted education.	https://www.marinepests.gov.au/sites/default/files/Documents/Project%20summary%20-%20Passive%20surveillance%2C%20education%2C%20and%20awareness%20of%20marine%20pests.pdf
Marine pests - Ports poster	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-ports-poster.pdf
Marine pests - Marinas poster	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-marinas-poster.pdf
Marine pests - Divers poster	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-divers-poster.pdf
Marine pests - Aquaculture poster	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-aquaculture-poster.pdf
Marine pests - Ports fact sheet	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-ports-fact-sheet.pdf
Marine pests - Marinas fact sheet	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-marinas-fact-sheet.pdf
Marine pests - Divers fact sheet – specialist divers	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-divers-fact-sheet-specialist-divers.pdf

Marine pests - Divers fact sheet – generalist divers	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-divers-fact-sheet-generalist-divers.pdf
Marine pests - Aquaculture fact sheet	Reporting a marine pest	https://www.marinepests.gov.au/sites/default/files/Documents/marine-pests-aquaculture-fact-sheet.pdf
Marine pests and how to identify them.	Reporting a marine pest	https://www.marinepests.gov.au/pests
The National Introduced Marine Pest Information System (NIMPIS)	Reporting a marine pest	https://www.marinepests.gov.au/pests/nimpis
Education and learning resources – (Victoria)	Education and learning resources	https://agriculture.vic.gov.au/biosecurity/marine-pests/education-and-learning-resources
Marine Pest Brochure (Queensland)	About marine pests and reporting	https://www.publications.qld.gov.au/dataset/prevent-marine-pests/resource/422c6d79-83b6-43e1-9299-9aa1cae9b806
Marine Pests: Look – Report – Protect (Queensland)	About marine pests and reporting	https://www.qld.gov.au/environment/coasts-waterways/marine-pests
Marine Pest Alert (NSW)	About marine pests and reporting	https://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/1582431/18300-marine-pest-ID-and-reporting-cards-V4-Acc.pdf
Marine pest advisory booklet for boaters and fishers (NSW)	Booklet on how to keep boats and fishing gears clean	https://www.dpi.nsw.gov.au/data/assets/pdf_file/0003/637590/marine-pests-booklet.pdf
Marine Pests in Southern NSW booklet for boaters and fishers	Booklet on how to keep boats and fishing gears clean	https://www.dpi.nsw.gov.au/data/assets/pdf_file/0004/637591/Marine-pests-in-southern-nsw.pdf

	Don't spread marine pests! - poster for boaters and fishers	About marine pests and reporting	https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0005/637592/Dont-spread-marine-pests.pdf
	Biofouling Primefact (Biofouling on recreational vessels) (NSW)	Biofouling on recreational vessels	https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0011/1395632/Primefact-Biofouling-on-recreational-vessels.pdf

International Policy Instruments

International Plant Protection Convention 1951
Convention on the Facilitation of International Maritime Traffic (FAL) as amended 1965
Convention on International Trade in Endangered Species (CITES) 1973
International Convention for Safety of Life at Sea (SOLAS) as amended including the ISM Code 1974
Convention on the Conservation of Migratory Species of Wild Animals (CMS) 1979
United Nations Convention on the Law of the Sea (UNCLOS) 1982
MARPOL 73/78, Annex IV 2003 & Annex V 1988
Convention on Biological Diversity (CBD) 1992
Rio Declaration and Agenda 21 1992
General Agreement on Trade and Tariffs (GATT) 1994
ICES Code of Practice on the Introduction and Transfer of Marine Organisms 1994
WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) 1995
FAO Code of Conduct for Responsible Fisheries and subsequent Technical Guidelines 1995
FAO Code of Conduct for the import and release of exotic biological control agents 1995
UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities 1995
Agreement for the Implementation of the Provisions of UNCLOS relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) 1995
London Convention 1972 & London Convention Protocol 1996
FAO guidelines on Precautionary Approach to Capture Fisheries (Including Species Introductions) 1996
Convention on the Law of Non-navigational Uses of International Watercourses 1997
International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) and the Seafarer's Training, Certification and Watchkeeping Code (STCW Code) 1978/95/97
Convention on International Civil Aviation (Resolution A-32-9 Preventing the Introduction of Invasive Alien Species) 1998
IUCN Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species 2000
Cartagena Protocol on Biosafety 2000
The Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2001
International Convention on the Control of Harmful Anti-fouling Systems on Ships (Anti-Fouling Convention) 2001
RAMSAR (Resolution VIII.18 Invasive species and wetlands) 2002
Codex Alimentarius (Code of Practice for Fish and Fishery Products) 2003
International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004
International Health Regulations (IHR) and plant and animal health agreements 2005
FAO guide: Aquaculture development. 2. Health management for responsible movement of live aquatic animals. 2007
FAO guide: Aquaculture development. 6. Use of wild fishery resources for capture-based aquaculture. 2011
World Organisation for Animal Health (OIE)'s Guidelines for assessing the risk of non-native animals becoming invasive. 2012
IMO Guidance for Minimizing the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft 2012
IMO Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species 2023
Manual of Diagnostic Tests and Vaccines for Terrestrial Animals 2024
Terrestrial Animal Health Code 2024
Manual of Diagnostic Tests for Aquatic Animals 2024
The Aquatic Animal Health Code 2024