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Malaysia's Status and Strategies in Mitigating the Invasive Aquatic Species for Biofouling Management

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Abstract
Biofouling is increasingly recognised as a major vector for the invasive aquatic species introduction (IAS), posing threats to marine biodiversity, national economic sectors, and public health. In Malaysia, the rapid growth of maritime activities, particularly in high-traffic zones, such as the Straits of Malacca, has elevated the risk of IAS transmission. This paper aims at assessing the national status assessment of biofouling management in Malaysia. Through literature reviews and focus group interview involving 67 respondents, this study investigates existing regulatory frameworks, examines pathways of biofouling and IAS transfer, and evaluates vulnerable marine sectors and ecosystems. The findings reveal that there is a need of a cohesive national framework to address biofouling risks, with current measures focused on ballast water management. Regulatory gaps, enforcement challenges, limited stakeholder coordination, and infrastructure constraints contribute to the situation. Sensitive marine habitats, including coral reefs, mangroves, seagrasses, and Ramsar-designated sites, remain particularly vulnerable. The study concludes by proposing a National Biofouling Strategy that integrates international guidelines with domestic policy mechanisms, enhances monitoring and enforcement capabilities, fosters inter-agency collaboration, and supports capacity-building initiatives. Through this strategic approach, Malaysia can better protect its marine biodiversity, sustain its maritime industries, and align with global commitments on environmental protection.
Keywords: invasive aquatic species, biofouling, National Biofouling Strategy, biodiversity

Introduction

Malaysia's maritime sector plays a pivotal role in its economic development, with shipping, fisheries, offshore oil and gas, and tourism collectively contributing a significant proportion of the national gross domestic product (GDP) (MIDA, 2021). Shipping alone facilitates more than 90% of Malaysia's international trade, while fisheries contribute approximately RM 16.5 billion annually to the economy, and marine-based tourism accounted for nearly RM 157 billion in 2023 (DOF, 2024; WTTC, 2024). Nonetheless, the increasing threat of invasive aquatic species (IAS) transmitted through biofouling has heightened concerns regarding the sustainability and resilience of these critical sectors. Biofouling, defined as the accumulation of aquatic organisms, such as barnacles, mussels, seaweeds, and microorganisms on submerged surfaces including ship hulls, offshore platforms, and aquaculture installations, acts as a primary vector for IAS dispersal across marine ecosystems (IMO, 2019).

The Strait of Malacca, a strategic international shipping lane, intensifies Malaysia's exposure to biofouling-mediated IAS introductions, as it handles approximately 94,000 vessel transits annually, making it one of the busiest maritime corridors in the world (Zhang, 2023; Rodrigue, 2024). Vessels operating in these high-traffic zones often carry fouling organisms from diverse bioregions, increasing the probability of non-native species establishing themselves in Malaysian waters. In addition to the biological risks, the economic consequences of unmanaged biofouling are considerable. Increased drag due to hull fouling can lead to up to a 40% rise in fuel consumption, significantly elevating operational costs for shipping companies, while also contributing to higher carbon emissions (Valchev et al., 2022). Maintenance costs are likewise inflated, as frequent dry-docking and hull cleaning become necessary to manage severe biofouling accumulations.

Beyond economic impacts, biofouling presents profound ecological threats by facilitating the establishment of non-native species that can outcompete native organisms, alter food webs, and degrade critical habitats such as coral reefs, seagrass beds, and mangrove forests (Romeu & Mergulhao, 2023). Sensitive marine ecosystems in Malaysia, already facing pressures from coastal development and climate change, are particularly vulnerable to the additional stresses introduced by IAS. Coral reefs, for instance, have experienced declining live coral cover in recent years, partially due to ecological disruptions linked to invasive species (Reef Check Malaysia, 2024).

Given these multifaceted threats, this research was conducted to investigate existing regulatory frameworks, examine pathways of biofouling and IAS transfer, and evaluate vulnerable marine sectors and ecosystems. This research aimed at providing strategic recommendations for strengthening Malaysia's marine biosecurity in alignment with international best practices.

Research Methodology

This research employed a multi-faceted methodology designed to comprehensively assess Malaysia's national preparedness in managing biofouling risks and preventing the introduction of invasive aquatic species (IAS). The study began with an extensive literature review, examining peer-reviewed articles, technical reports, international guidelines such as the Biofouling Guidelines IMO 2023 Biofouling Guidelines (MEPC.378(80)) (IMO, 2023), and conventions including the Ballast Water Management Convention, the International Convention on the Control of Harmful Anti-Fouling Systems (AFS Convention), and the United Nations Convention on the Law of the Sea (UNCLOS). This review established a foundational understanding of global best practices and standards relevant to marine biosecurity and biofouling management.

Simultaneously, the research undertook a critical analysis of Malaysia's national legal and policy frameworks by focusing on instruments, such as the Merchant Shipping Ordinance 1952 (MSO 1952), the Environmental Quality Act 1974 EQA 1974), and relevant Malaysia Shipping Notices (MSN). These documents were scrutinised to evaluate the extent of regulatory coverage and to detect gaps or overlaps that may influence the country's ability to address biofouling and associated IAS risks effectively.

To complement the document-based analysis, the study incorporated a series of focus group interviews and stakeholder consultations involving 67 participants from key sectors, including government agencies such as the Malaysia Marine Department (MMD) and the Department of Fisheries (DOF), port authorities including Port Klang and Port of Tanjung Pelepas (PTP), the offshore oil and gas industry represented by companies like Petroliam Nasional Berhad (PETRONAS), as well as experts from academia and environmental organisations. Participants were strategically selected to ensure coverage of all major stakeholder groups engaged in maritime operations and environmental management.

The study adopted a qualitative research design by utilising semi-structured interview techniques that allowed for flexible, yet targeted discussions around regulatory frameworks, operational practices, infrastructure adequacy, stakeholder awareness, and monitoring capacities related to biofouling management. Questions were structured to elicit detailed perspectives on perceived challenges, priority areas for improvement, and institutional responsibilities.

Data collected from the interviews and consultations were subjected to thematic analysis. This approach involved coding responses into emergent themes such as regulatory gaps, enforcement challenges, infrastructure limitations, stakeholder coordination, and capacity-building needs. Patterns and recurrent issues were identified and cross-validated against findings from the literature and policy reviews to ensure triangulation and strengthen the validity of the results (Braun & Clarke, 2006). Through this rigorous methodological framework, the study synthesised a comprehensive understanding of Malaysia's status, vulnerabilities, and opportunities for strengthening biofouling management in culminating in a set of evidence-based recommendations tailored to Malaysia's maritime and environmental contexts.

Results

The findings clearly indicate that Malaysia's marine waters are highly vulnerable to the introduction of invasive aquatic species (IAS), primarily through ballast water and increasingly through biofouling. While regulatory measures, such as pre-arrival notifications and Port State Control (PSC) inspections exist, primarily targeting ballast water, biofouling remains under-regulated despite being recognised as a significant secondary pathway for IAS transfer. Although Malaysia's legislative framework includes the Merchant Shipping Ordinance 1952 (MSO 1952) and the National Action Plan on Invasive Alien Species 2021–2025, these instruments offer only partial coverage, focusing mainly on shipping activities and lacking comprehensive control over other maritime pathways.

The findings also highlight that Malaysia's current biofouling management efforts are fragmented and insufficient, with no dedicated national biofouling strategy in place. Coordination among agencies, such as the Ministry of Transport (MOT), Malaysia Marine Department (MMD), Department of Fisheries (DOF), Department of Environment (DOE), and Malaysia Maritime Enforcement Agency (MMEA), occurs through platforms like the National Committee on Invasive Alien Species, yet overall integration and operational effectiveness require substantial enhancement. Ports currently lack standardised protocols for hull inspections, and underwater cleaning practices are largely unregulated, thus further exacerbating the risks of IAS spread.

Several critical gaps were also identified, including the absence of an integrated ocean governance framework, weak inter-agency coordination, enforcement challenges, limited public awareness regarding IAS threats, and the need for a robust monitoring and evaluation system. Additionally, Malaysia's infrastructure to manage biofouling waste remains inadequate, and technical capacity among regulatory personnel requires strengthening.

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In response to these challenges, the study proposes the urgent development of a National Biofouling Strategy. This strategy should align with international standards, particularly the Biofouling Guidelines IMO 2023 Biofouling Guidelines (MEPC.378(80)), while being tailored to Malaysia's specific maritime context. Key recommendations include the establishment of national legislation specific to biofouling, standardised hull inspection and maintenance protocols, upgrading of port reception facilities for eco-friendly in-water cleaning, and the mandatory use of non-toxic antifouling systems. Capacity-building programmes targeting ship operators, enforcement agencies, and port workers, alongside nationwide stakeholder engagement campaigns, are crucial to raise awareness and promote compliance.

Furthermore, the creation of a national biofouling surveillance database and increased investment in marine research are essential to support data-driven and adaptive management approaches. Addressing these gaps through a comprehensive and integrated biofouling management framework is vital to safeguarding Malaysia's rich marine biodiversity and ensuring the long-term sustainability of its maritime industries.

Discussion

Malaysia's Current Regulatory Framework

Malaysia's current marine environmental protection efforts are heavily skewed toward ballast water management, following its ratification of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) in 2011. In response, Malaysia operationalised the BWM Convention through the issuance of multiple Malaysia Shipping Notices (MSN) by the Malaysia Marine Department (MMD), notably MSN 05/2017 and MSN 14/2023, which outline procedures for ballast water management and compliance inspections at Malaysian ports. These measures demonstrate Malaysia's commitment to international marine biosecurity standards concerning ballast water as a vector for invasive aquatic species (IAS).

Nonetheless, despite these efforts, it is found that there is no specific legislation that directly addresses biofouling management in Malaysia. The Merchant Shipping Ordinance 1952 (MSO 1952) and the Environmental Quality Act 1974 (EQA 1974), while covering general marine pollution issues, offer only partial protection against marine environmental risks and do not explicitly target biofouling vectors, such as hull fouling, niche area accumulation, or the movement of offshore mobile structures (DOE, 2005; Mohd Zaideen, 2019). The MSO 1952 primarily governs vessel registration, crew certification, and general pollution prevention but lacks provisions that require vessels to manage or report hull fouling. Similarly, the EQA 1974 focuses on controlling emissions, effluents, and discharges from land-based activities but does not extend to comprehensive biofouling or vessel-related IAS risk management (DOE, 2005).

Malaysia has ratified key international instruments that touch upon marine environmental protection, including the United Nations Convention on the Law of the Sea (UNCLOS) 1982, the Convention on Biological Diversity (CBD) 1992, and the International Convention on the Control of Harmful Anti-fouling Systems (AFS Convention) (IMO, 2001). UNCLOS obliges coastal states to prevent, reduce, and control pollution of the marine environment from vessels, while the CBD mandates the control or eradication of alien species that threaten ecosystems. The AFS Convention regulates the use of harmful substances in antifouling systems on ships, aiming to minimise environmental damage from toxic coatings. Nonetheless, while Malaysia is a signatory to these conventions, the integration of their specific provisions related to biofouling into domestic law remains limited and fragmented (IMO, 2001).

The absence of a targeted national legal framework for biofouling management represents a significant regulatory gap. Malaysia's current measures primarily rely on general maritime pollution control and ship safety regulations without addressing the complexities of IAS transmission through hull fouling or mobile infrastructure. This gap results in insufficient regulatory leverage to impose preventative biofouling controls, mandate vessel biofouling management plans, or conduct risk-based hull inspections beyond ballast water considerations. Consequently, Malaysia faces challenges in proactively managing biofouling risks at ports, within the offshore oil and gas sector, and in emerging industries such as aquaculture and maritime renewable energy installations.

Given the increasing global attention to biofouling as a major IAS vector and considering new international developments, such as the 2023 revision of the IMO Biofouling Guidelines (MEPC.378(80)), Malaysia would benefit from developing a national biofouling strategy supported by dedicated legislation. Such a strategy should harmonise with existing international commitments while addressing domestic maritime industry needs, particularly in relation to port state control practices, hull cleaning standards, eco-friendly antifouling technologies, and the establishment of port reception facilities for biofouling waste.

Biofouling and Invasive Aquatic Species (IAS) Transfer Pathways

The assessment revealed that Malaysia faces multiple biofouling-related pathways for invasive aquatic species (IAS) introduction. International shipping remains the dominant pathway, with ballast water discharges and hull fouling being major concerns. Mobile offshore units such as drilling platforms, support vessels, and floating production storage and offloading (FPSO) also represent significant risks due to prolonged deployment and complex biofouling communities (GlobalData, 2024). Secondary vectors include domestic vessel traffic, aquaculture infrastructure, in-water hull cleaning practices, and marine debris acting as floating rafts for organisms (Kim et al., 2024; NOAA, 2017). The cumulative risks are intensified in major Malaysian ports like Port Klang, Tanjung Pelepas, and Penang, with increased ship traffic, stationary periods, and facility usage contributing to the potential establishment of IAS populations.

Vulnerable Marine Ecosystems and Socio-Economic Sectors

Malaysia's rich marine biodiversity, encompassing critical ecosystems, such as coral reefs, mangroves, seagrass meadows, Ramsar-designated wetlands, and United Nations Educational, Scientific, and Cultural Organization (UNESCO) biosphere reserves, is increasingly under considerable threat from the introduction and spread of invasive aquatic species (IAS) through biofouling pathways. Coral reefs, which support an estimated 25% of all marine species and are essential to both the fisheries and tourism sectors, have already shown alarming signs of ecological stress. Data from Reef Check Malaysia (2024) indicate that live coral cover in Malaysian waters declined from 47.83% in 2022 to 45.87% in 2023, a worrying trend that reflects both environmental degradation and biological disturbances potentially exacerbated by IAS colonisation. These reefs not only sustain critical fisheries resources but also serve as major attractions for Malaysia's vibrant marine tourism industry.

Mangrove forests, which cover approximately 577,500 hectares in Malaysia, play an equally vital role by stabilising coastlines, sequestering carbon, and serving as nurseries for commercially important fish species. Nevertheless, IAS pose serious threats to these ecosystems by outcompeting native mangrove-associated fauna and altering key ecological processes (ADB, 2014). The introduction of non-native organisms can disrupt nutrient cycling, diminish fishery productivity, and compromise the resilience of mangrove systems to climate change impacts.

Seagrass meadows, found in shallow coastal areas, like those in Pulau Redang and Pulau Langkawi, are also highly vulnerable to IAS. These habitats provide critical foraging grounds for endangered species such as dugongs and green turtles, and their degradation could have cascading effects on Malaysia's marine biodiversity (Sidik, 2012). Ramsar-designated wetlands, including the Tanjung Piai and Pulau Kukup sites, which are recognised for their international ecological importance, are likewise at risk from IAS encroachment that could undermine their protective functions and biodiversity value (UNESCO, 2023).

Economically, the consequences of unchecked IAS proliferation are profound. The fisheries sector contributed RM 16.5 billion to Malaysia's economy in 2023, underpinning food security, livelihoods, and export earnings (DOF, 2024). The aquaculture industry, valued at RM 3.9 billion, depends heavily on clean and biologically stable marine and brackish water systems for species cultivation, thus making it particularly sensitive to IAS outbreaks that can introduce new pathogens, reduce water quality, and increase operational costs. Additionally, the marine tourism sector, valued at approximately RM 157 billion in 2024, relies on the health and aesthetic appeal of coral reefs, pristine beaches, and coastal ecosystems (WTTC, 2024). The degradation of these natural assets by invasive species would not only erode tourism revenue but could also result in significant socio-economic repercussions for coastal communities dependent on tourism-driven employment.

Thus, the protection of Malaysia's marine ecosystems from IAS threats is not solely an environmental imperative but a socio-economic necessity. Strengthening biofouling management measures, particularly at high-risk hubs, such as ports, offshore installations, and aquaculture sites, is essential to safeguarding both Malaysia's biodiversity heritage and the economic sectors intrinsically linked to healthy marine environments.

Conclusion

Malaysia's marine ecosystems and maritime economy face mounting threats from the introduction of invasive aquatic species (IAS), significantly driven by unmanaged biofouling on vessels and offshore structures. Biofouling-mediated IAS introductions disrupt native biodiversity, degrade critical habitats like coral reefs and mangroves, and threaten sectors such as fisheries, aquaculture, and marine tourism. This research highlights critical gaps in Malaysia's current management, including fragmented regulations, weak enforcement, and insufficient coordination across agencies. Existing frameworks mainly address ballast water and toxic antifouling systems, hence leaving biofouling as an under-regulated pathway.

In response, there is an urgent need for a cohesive National Biofouling Strategy that harmonises international best practices, particularly the IMO 2023 Biofouling Guidelines (MEPC.378(80)), with Malaysia's unique maritime and environmental contexts. A robust strategy would enhance ecosystem resilience, secure economic

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livelihoods dependent on marine resources, and reaffirm Malaysia's commitment to global ocean stewardship under frameworks like the Sustainable Development Goals (SDG 14) and the Convention on Biological Diversity. Proactive biofouling management is essential for safeguarding Malaysia's marine heritage and ensuring the long-term sustainability of its maritime economy.

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