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MARITIME INFRASTRUCTURE IMPACTS ON MARINE SOCIO-ECOLOGICAL SYSTEMS: A LITERATURE REVIEW

S.J.L. Madhushani[1], K.A.T.O. Ranadewa[2], and B.A.K.S. Perera[3]

ABSTRACT

Maritime infrastructure plays a pivotal role in supporting economic development, energy transition, and global maritime connectivity. However, its interactions with Marine Socio-Ecological Systems (MSES) are complex and multifaceted. While previous studies have examined ecological or socio-economic impacts in isolation, there is a paucity of research integrating these impacts within the broader context of MSES. This study addresses this gap through a comprehensive literature review and synthesis of empirical and theoretical studies on maritime infrastructure. Findings indicate that maritime infrastructure provides numerous positive impacts on MSES, including enhanced biodiversity, fisheries productivity, habitat complexity, renewable energy generation, coastal protection, and socio-economic resilience. Simultaneously, it generates negative impacts, including habitat loss, ecological fragmentation, disruption of major ecological processes, pollution, and reduced adaptive capacity of coastal communities. The study underscores the need for integrated, nature-inclusive design and governance strategies to balance economic development with ecological sustainability, thereby ensuring the long-term resilience and multifunctionality of MSES.

Keywords: *Marine Socio-ecological Systems; Maritime Infrastructure; Negative Impacts; Positive Impacts.*

1. INTRODUCTION

It is well recognised that human well-being and economic development are fundamentally dependent on natural ecosystems (Heslinga et al., 2017). Many studies highlight that humans constantly rely on natural systems, emphasising the concept of 'humans-in-nature' (Petrosillo et al., 2015). However, human activities are increasingly transforming natural ecosystems in complex and uncertain ways (Fischer et al., 2015), resulting in multiple environmental problems, including biodiversity loss and resource depletion. Solving such issues requires integrated perspectives that move beyond traditional disciplinary boundaries (Virapongse et al., 2016). Hence, the concept of Socio-Ecological Systems (SES) has emerged to understand the dynamic relationships between humans and nature (Heslinga et al., 2017). SES refers to interconnected systems in which

[1] Research Assistant, Department of Building Economics, University of Moratuwa, Sri Lanka, madhushanisjl.20@uom.lk

[2] Senior Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, tharushar@uom.lk

[3] Senior Professor, Department of Building Economics, University of Moratuwa, Sri Lanka, kanchana@uom.lk

ecological and social components interact through feedback mechanisms across multiple spatial and temporal scales (Fischer et al., 2015; Virapongse et al., 2016). The ecological component of SES provides essential ecosystem services, including food, energy, water, and raw materials that support humans (Heslinga et al., 2017). On the other hand, human activities influence ecological processes through resource extraction and other anthropogenic pressures (Virapongse et al., 2016). Understanding these interdependencies is therefore essential. Consequently, the SES perspective has been explored in multiple fields, including environmental management (Smith et al., 2025), climate change (Kanan & Giupponi, 2024), marine systems (Lazzari et al., 2026), and agriculture (Salazar-Gálvez et al., 2026). Among these, oceans and marine environments represent one of the most complex socio-ecological systems on the planet (Bugnot et al., 2020). Oceans constitute the largest ecosystem on Earth (Spanier & Kuenzer, 2024). They support diverse biological communities while providing critical ecosystem services (Hryshyna et al., 2021). However, growing anthropogenic pressures place significant stress on marine ecosystems (Banihabib & Assadi, 2023). Thus, MSES have become a central global concern (Glaser & Glaeser, 2014). MSES involves complex interactions between ecological components such as marine habitats and oceanographic processes, and social components including coastal communities and institutions, and economic activities (Ferrol-Schulte et al., 2013; Refulio-Coronado et al., 2021). MSES are influenced by a plethora of ocean-based activities (Villasante et al., 2013), including fisheries, marine tourism, coastal development, marine renewable energy, and marine biotechnology (Bugnot et al., 2020). Among these, maritime infrastructure plays a significant role within the domain of marine and coastal development (Li et al., 2022).

Maritime infrastructure forms a critical component of global maritime development (Zimmerhackel et al., 2023). It encompasses diverse infrastructure types, including ports and harbours, offshore energy infrastructure, coastal defence structures, artificial islands, pipelines, aquaculture facilities, and undersea cables, each characterised by distinct features (Hryshyna et al., 2021; Li & Li, 2007). These infrastructures are considered major enablers that facilitate international trade, support maritime transportation networks, enable offshore industries, and contribute to coastal economic growth (Hooper et al., 2021). Prior studies have consistently emphasised offshore energy infrastructure (offshore wind farms and offshore oil and gas platforms), ports and harbours, and coastal defence infrastructure (seawalls and breakwaters) as significant infrastructure types generating multiple impacts (Allen & Moore, 2016; Banihabib & Assadi, 2023; Dafforn et al., 2015; Marnot, 2025; Watson et al., 2024). Therefore, in the present study, maritime infrastructure primarily refers to these three infrastructure categories. Notably, the development of such infrastructure produces both positive and negative ecological and social impacts on MSES (Airoldi & Bulleri, 2011). Although a growing body of literature has examined MSES (Berkes, 2011; Glaser & Glaeser, 2014; Villasante et al., 2013), studies often focus on specific sectors or isolated environmental impacts. Moreover, seminal studies by Bugnot et al. (2020) primarily focused on mapping the current and projected global extent of marine built structures and assessing their broad seascape-scale ecological modifications and physical footprints. Similarly, Bulleri and Chapman (2010) explored primarily on the ecological consequences of coastal urban infrastructure, particularly artificial shoreline structures, with emphasis on habitat alteration, biodiversity impacts, and ecological engineering approaches. Consequently, the broader implications of maritime infrastructure within the domain of MSES remain insufficiently explored. Therefore, this study aims to contribute to the existing literature by examining the impacts of maritime infrastructure on MSES through two objectives. These are: (i) to identify the positive impacts of maritime infrastructure on MSES, and (ii) to identify the negative impacts of maritime infrastructure on MSES. The paper's underlying sections include the literature review, methodology, research findings, discussion, and conclusions.

2. LITERATURE REVIEW

2.1 MARINE SOCIO-ECOLOGICAL SYSTEMS

Tropical marine environments have supported human communities for centuries (Berkes, 2011). The concept of MSES has therefore emerged to understand the multidimensional relationships between people and marine ecosystems (Ferrol-Schulte et al., 2013). As illustrated in Figure 1, MSES consists of interconnected social and ecological components linked through multiple interactions and feedback mechanisms (Elegbede et al., 2023; Villasante et al., 2013). These interactions include resource use, governance decisions, technological interventions, and ecological responses that operate across different spatial and temporal scales (Ellis et al., 2025).

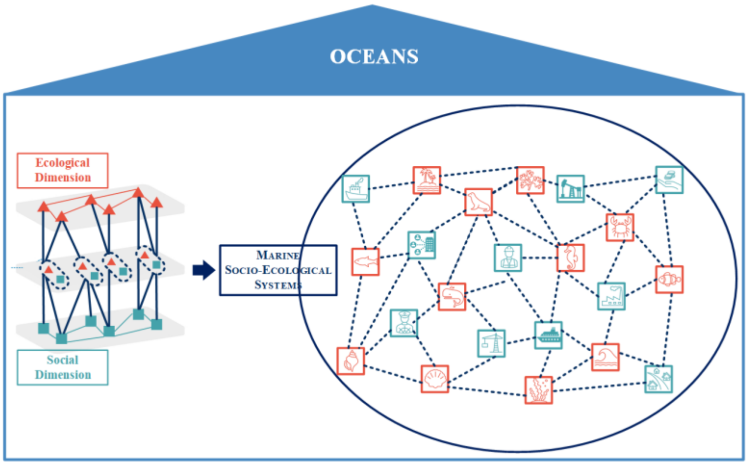

Figure 1: Marine socio-ecological systems

As presented in Figure 1, in MSES, ecological conditions influence human livelihoods, while human activities simultaneously influence ecological structures (Berkes, 2011). However, increasing anthropogenic pressures, including overfishing, habitat destruction, and pollution, disrupt the balance between ecological integrity and human use (Berkes, 2011). MSES are, therefore, characterised by high levels of complexity, uncertainty, and vulnerability (Coronado et al., 2021). Thus, effective governance mechanisms and management frameworks play a critical role in securing the overall functioning of MSES (Glaser & Glaeser, 2014). Within the broader spectrum of components and frameworks affecting MSES, maritime infrastructure has emerged as a key driver influencing the MSES (Spanier & Kuenzer, 2024).

2.2 MARITIME INFRASTRUCTURE

Maritime infrastructure is generally considered the most prominent anthropogenic modification to the global seascape (Hofstede & Koningsveld, 2024). They refer to the engineering structures and facilities located in marine environments (Hryshyna et al., 2021; Li & Li, 2007). Given the diversity of maritime activities, maritime infrastructure encompasses a wide range of structural forms and functional purposes (Abdolpour & Marut, 2025). Scholars have therefore categorised maritime infrastructure from several perspectives. One common classification is based on location, distinguishing infrastructure situated in coastal, nearshore, offshore, and inland waterway environments (Amaechi et al., 2022; Gourvenec, 2018; Li & Li, 2007). Another widely used approach categorises infrastructure according to the functional applications, such as maritime transportation, offshore energy, fisheries, tourism, and coastal protection (Banihabib & Assadi, 2023; Marnot, 2025). From an engineering perspective, maritime infrastructure can be classified as fixed, floating, and submerged structures (Mohapatra, 2022). In the context of MSES, maritime infrastructure represents a critical physical link between human activities and marine ecosystems (Bugnot et al., 2020). On one hand, maritime infrastructure supports maritime industries and livelihoods (Whoriskey et al., 2021). On the other hand, the construction and operation of maritime infrastructure can significantly alter marine environments (Airoldi & Bulleri, 2011). Thus, it is noteworthy to explore the potential impacts of maritime infrastructure on MSES.

3. RESEARCH METHODOLOGY

A comprehensive literature review is critical for strengthening any research as it critically examines existing knowledge, identifies gaps, and establishes a robust foundation for new contributions (Neubert, 2026). Standalone literature reviews consolidate fragmented findings and develop an integrated perspective (Taherdoost, 2023). Among diverse approaches, narrative literature reviews focus on the critical synthesis of existing studies to develop a coherent understanding of the subject (Sukhera, 2022). Narrative reviews are particularly valuable when the research domain consists of diverse perspectives, heterogeneous evidence, and fragmented relationships that require in-depth conceptual interpretation (Usman et al., 2025). Unlike bibliometric analysis, which primarily emphasises publication patterns and citation structures, or systematic review approaches such as PRISMA, the narrative literature review approach enables a more flexible and holistic exploration of research domain (Belter, 2015; Mishra & Mishra, 2023). Given the interdisciplinary nature of the research topic, existing studies are highly fragmented across environmental science, marine ecology, coastal engineering, maritime development, and socio-economic research domains. Consequently, an in-depth qualitative content analysis and interpretive synthesis are necessary to comprehensively examine the diverse perspectives reported across the literature. Therefore, this study adopts a narrative literature review approach to examine the impacts of maritime infrastructure on MSES. Literature was collected from databases, including Google Scholar, Scopus, and Web of Science. These databases were selected for their comprehensive coverage of multidisciplinary, peer-reviewed literature, ensuring the inclusion of both ecological and socio-economic perspectives (Martín-Martín et al., 2018). Three groups of keywords were identified and combined using Boolean logic appropriate to each database: (i) maritime infrastructure-related terms, (ii) MSES concepts, and (iii) impact-related terms. Accordingly, the key search terms included: ("maritime infrastructure" OR "marine infrastructure" OR "offshore infrastructure" OR "coastal infrastructure") AND ("marine socio-ecological systems" OR "socio-ecological systems" OR "MSES" OR "SES") AND ("impact" OR "effect" OR "benefit" OR "risk" OR "positive" OR "negative" OR "challenge" OR "pressure" OR "trade-off"). Figure 2 presents the research process of the present study.

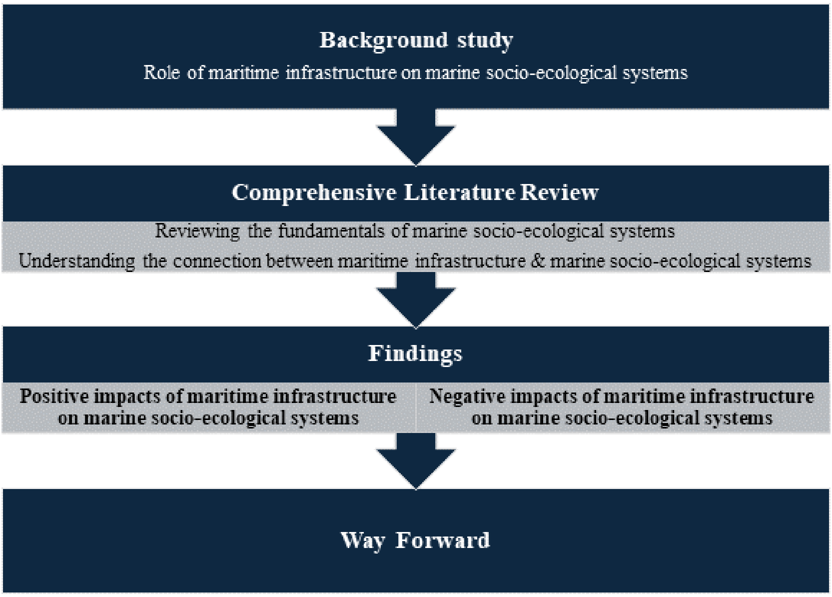

Figure 2: Research process

Accordingly, a background study was conducted to understand the role and impacts of maritime infrastructure on MSES. This was followed by a comprehensive literature review of maritime infrastructure and MSES. Data analysis was conducted using manual content analysis, chosen for its ability to sensitively accommodate diverse literature (Anastasiei & Georgescu, 2020). Manual coding was employed to categorise the data into key themes and sub-themes, allowing for a comprehensive understanding of the multidimensional impacts of maritime infrastructure on MSES. Initially, relevant literature extracts were carefully reviewed and segmented to identify recurring concepts and patterns (Vollstedt & Rezat, 2019). These initial codes were then progressively compared and grouped based on conceptual similarity, allowing higher-order categories to emerge through iterative refinement, ensuring broader analytical structures aligned with the research objectives (Williams & Moser, 2019). A three-level coding structure was subsequently developed and applied to enhance clarity, and consistency. Accordingly, Level 1 distinguished the overarching systems as the social system and ecological system. Level 2 classified the direction of impacts into positive and negative impacts. Level 3 further refined the analysis by categorising impacts into environmental, social, and economic subcategories.

4. FINDINGS

4.1 IMPACTS OF MARITIME INFRASTRUCTURE ON MARINE SOCIO-ECOLOGICAL SYSTEMS

Maritime infrastructure, as a core pillar of coastal and marine environments, generates both positive and negative impacts that influence MSES (Abdolpour & Marut, 2025; Bugnot et al., 2020). Understanding these dual effects is therefore essential to ensure that maritime infrastructure development supports the long-term resilience of MSES.

4.2 Positive Impacts of Maritime Infrastructure on Marine Socio-Ecological Systems

Existing literature increasingly emphasises that maritime infrastructure provides enormous positive impacts on MSES (Bugnot et al., 2020). Table 1 synthesises the positive impacts, illustrating the diverse contributions of maritime infrastructure to MSES. Accordingly, maritime infrastructure offers substantial contributions to the structure, function, and resilience of MSES. Economically, maritime infrastructure supports the development of coastal and offshore regions by enabling ports, and offshore industrial facilities, which collectively strengthen regional livelihoods, enhance community resilience, and facilitate the sustainable integration of human activities within MSES (Hryshyna et al., 2021; Park & Kildow, 2015; Spanier & Kuenzer, 2024). The rapid growth of ocean-based industries highlights the pivotal role of maritime infrastructure in optimising the use of ocean space, promoting employment, and creating economic opportunities (Allen & Moore, 2016; Li et al., 2022). From an energy transition perspective, maritime infrastructure enables renewable and green energy generation, supporting the shift away from fossil-fuel-based systems and contributing to the sustainability of MSES (Bugnot et al., 2018); however, these outcomes depend on design choices, ecological sensitivities, and regulatory frameworks (Bugnot et al., 2020; Spanier & Kuenzer, 2024). Environmentally, maritime structures can enhance MSES functionality by providing habitat complexity, and supporting fisheries productivity (Dafforn et al., 2015; ter Hofstede & van Koningsveld, 2024). By functioning as artificial reefs or colonisation substrates, maritime infrastructures strengthen ecological connectivity and improve the resilience of both ecological and human components of MSES (Hooper et al., 2021). Eco-engineered and nature-inclusive designs further improve ecological resilience and provide coastal protection against erosion and wave energy impacts (Li et al., 2022; Allen & Moore, 2016). From a social perspective, maritime infrastructure contributes to the adaptive capacity of MSES by improving coastal protection, reducing erosion, and enhancing maritime safety (Allen & Moore, 2016; Park, 2014). Moreover, it promotes adaptive capacity in coastal communities (Li et al., 2022). Collectively, these positive impacts demonstrate maritime infrastructure as a critical enabler of multifunctional, resilient, and sustainable MSES. However, compared with environmental impacts, social and economic impacts remain less frequently explored, suggesting a gap in understanding the socio-economic dimensions of maritime infrastructure impacts in MSES. Despite these widely recognised positive impacts, maritime infrastructure also generates negative impacts on MSES.

4.3 Negative Impacts of Maritime Infrastructure on Marine Socio-Ecological Systems

Despite multiple positive impacts, a growing body of literature highlights that maritime infrastructure generates significant adverse impacts on MSES (Afzal et al., 2022). Physical alterations of seabed morphology, intensive dredging (Fernandes et al., 2023), and land reclamation (Shan & Li, 2020) disrupt the natural dynamics of MSES (Watson et al., 2024). Thus, maritime infrastructure is increasingly recognised as a key anthropogenic driver of habitat loss, and deterioration of marine environmental quality (Chen & Wang, 2023). Accordingly, Table 1 synthesises the diverse perspectives within the existing literature, presenting a comprehensive overview of the negative impacts of maritime infrastructure on MSES.

Table 1: Positive and negative impacts of marine infrastructure on marine socio-ecological systems

Ecological System		**Social System**	
Positive Impacts of Marine Infrastructure on Marine Ecological Systems	**Negative Impacts of Marine Infrastructure on Marine Ecological Systems**	**Positive Impacts of Marine Infrastructure on Marine Social System**	**Negative Impacts of Marine Infrastructure on Marine Social System**
<u>Environmental Impacts</u> • Enable the generation of renewable and green energy from marine resources [1],[2],[3],[4],[5],[6],[7],[8] • Support the transition from fossil-based systems to sustainable energy pathways [1],[2],[3],[4],[5],[6],[7] • Enhance fisheries productivity by providing habitat for marine organisms [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11] • Provide effective coastal protection by reducing wave energy and shoreline erosion [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11] • Enhance ecological connectivity and support species dispersal under changing climatic conditions [1],[2],[3],[4],[5],[6],[7],[8] • Increase marine biodiversity by functioning as artificial reefs and colonisation substrates [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12],[13]	**<u>Environmental Impacts</u>** • Disruption of ecosystems previously supported by offshore platforms during decommissioning or dismantling [1],[6],[7],[8],[10],[11],[30],[31],[49],[51] • Degradation, destruction, and fragmentation of critical marine habitats [1],[6],[7],[8],[10],[11],[12],[13],[30],[31],[32],[33],[34],[35],[36],[37],[38],[39],[40],[41],[50] • Loss of ocean wilderness and reduced ecosystem resilience [7],[11],[30],[31] • Alteration of physical and chemical properties of water, including hydrodynamics, and sediment characteristics [13],[30],[31],[32],[33],[34],[35],[36],[37],[38],[49],[50] • Disruption of ecological processes (organism movement, food webs, propagule dispersal, and energy flow) [1],[13],[36],[37],[38],[39],[40],[44],[45],[46] • Spread of non-indigenous/ invasive species, altering local ecosystem dynamics [1],[6],[7],[8],[10],[11],[12],[13],[30],[31],[32],[33],[34],[51] • Increased suspended sediments and turbidity during dredging, affecting water quality and marine life [1],[6],[7],[8],[10],[11],[12],[13],[30],[31],[40],[43] • Shoreline erosion, overtopping, and armour stone instability impacting habitats [1],[6],[7],[8],[10],[11],[30],[31],[42],[50]	**<u>Social Impacts</u>** • Improve food security through increased availability of marine biological resources [1],[2],[3],[4],[5],[6],[7] • Improve maritime safety by creating calm waters for harbour operations [1],[2],[3] • Support recreation, tourism, and environmental education activities [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12],[13],[14],[15] • Support integrated ocean governance and strategic marine policy implementation [1],[2],[3],[4],[5],[6],[7],[8] **<u>Economic Impacts</u>** • Promote economic development through ports and offshore industrial facilities [1],[2],[3],[4],[5],[6],[7],[8],[9],[10] • Strengthen global maritime connectivity and facilitate international trade [1],[2],[3],[4] • Enable offshore exploration and production of oil and gas resources in deep-water [1],[2],[3],[4],[5]	**<u>Social Impacts</u>** • Reduced adaptive capacity of coastal communities to sea level rise increasing vulnerability of settlements and livelihoods [1],[6],[7],[30],[31],[44],[45],[46] **<u>Economic Impacts</u>** • Cumulative environmental degradation (overexploitation of fisheries and depletion of marine resources), affecting food security and local economies [1],[6],[7],[8],[10],[11],[12], [30],[31] • Economic losses to coastal communities resulting from infrastructure failures [1],[6],[7],[8],[10],[30],[31],[47],[48]

Ecological System		Social System	
Positive Impacts of Marine Infrastructure on Marine Ecological Systems	**Negative Impacts of Marine Infrastructure on Marine Ecological Systems**	**Positive Impacts of Marine Infrastructure on Marine Social System**	**Negative Impacts of Marine Infrastructure on Marine Social System**
• Improve ecological resilience through eco-engineered and nature-inclusive designs [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12],[13] • Deliver ecosystem services; pollution reduction and water quality improvement [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12] • Allow versatile application across coastal, offshore, and deep-sea environments through diverse structural types [1],[2],[3],[4],[5],[6]	• Habitat loss and modification due to land reclamation and artificial islands [6],[7],[30],[31],[51] • Pollution from untreated discharges, production wastes, or human activity affecting surrounding ecosystems [1],[6],[7],[30],[31],[32],[33],[34],[35],[36],[41] • Replacement of natural habitats with built structures, modifying seascapes and environmental conditions [1],[6],[7],[8],[36],[37],[38],[39],[40],[47],[48],[51] • Sub-lethal biological impacts, including reduced reproduction, disorientation [1],[6],[7],[8],[10],[11],[12],[13],[30],[31],[32],[33]	• Support efficient utilisation of ocean space for energy recovery [1],[2],[3],[4],[5],[6],[7] • Facilitate the development of emerging marine industries [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11] • Promote long-term marine infrastructure development and continuous technological advancement [1],[2],[3],[4],[5],[6],[7],[8],[9] Optimise local resource efficiency and support regional socio-economic development [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12]	

[1] (Allen & Moore, 2016), [2] (Bugnot et al., 2018), [3] (Park & Kildow, 2015), [4] (Abdolpour & Marut, 2025), [5] (Park, 2014), [6] (Spanier & Kuenzer, 2024), [7] (Li & Li, 2007), [8] (Hryshyna et al., 2021), [9] (Sadeghi, 2008), [10] (ter Hofstede & van Koningsveld, 2024), [11] (Dafforn et al., 2015), [12] (Li et al., 2022), [13] (Bulleri & Chapman, 2010), [14] (Griffin et al., 2019), [15] (Paxton, Lester, et al., 2025), [16] (Whoriskey et al., 2021), [17] (Paxton, Runde, et al., 2025), [18] (Banerjee et al., 2018), [19] (Pioch et al., 2011), [20] (Zimmerhackel et al., 2023), [21] (Wang et al., 2020), [22] (Gao et al., 2020), [23] (Cisneros-Montemayor & Sumaila, 2010), [24] (Hooper et al., 2021), [25] (Sutton-Grier et al., 2015), [26] (Perkol-Finkel & Sella, 2014), [27] (Korbee & Van Tatenhove, 2013), [28] (Glykas et al., 2010), [29] (Li, 2023), [30] (Bugnot et al., 2020), [31] (Nassar & Elbisy, 2024), [32] (Morris et al., 2018), [33] (Bueger & Liebetrau, 2023), [34] (Fowler et al., 2018), [35] (McKibbin et al., 2024), [36] (Wilson et al., 2015), [37] (Lennox et al., 2025), [38] (Dreizis et al., 2019), [39] (Komyakova et al., 2022), [40] (Valdez et al., 2016), [41] (Chen & Wang, 2023), [42] (Anton et al., 2019), [43] (El Gohary & Hassan, 2012), [44] (Yuan et al., 2023), [45] (Kuşku et al., 2018), [46] (Lopes et al., 2025), [47] (Del Grosso, 2001), [48] (Ware & Callaway, 2019), [49] (Sheehan et al., 2020), [50] (Airoldi & Bulleri, 2011), [51] (van Elden et al., 2025)

As presented in Table 1, existing literature consistently highlights maritime infrastructure as a major driver of disturbances within MSES, particularly from an environmental perspective. Empirical studies demonstrate that activities including dredging, land reclamation, and offshore installations cause degradation, fragmentation, and permanent loss of critical marine habitats (Ware & Callaway, 2019). Consequently, they reduce the resilience of both ecological and social components of MSES (Spanier & Kuenzer, 2024; ter Hofstede & van Koningsveld, 2024). Physical modifications associated with maritime infrastructure activities erode shorelines and destabilise protective coastal structures, collectively impairing water quality and ecosystem functions (Allen & Moore, 2016; Nassar & Elbisy, 2024). Moreover, maritime infrastructure disrupts vital ecological processes that sustain MSES, including organism movement, propagule dispersal, energy flow, and food-web connectivity (Bugnot et al., 2020; Li & Li, 2007). These disruptions can facilitate the spread of invasive or non-indigenous species, further disturb local ecosystem dynamics and undermine the adaptive capacity of coastal communities (Sheehan et al., 2020). Beyond environmental impacts, the literature also emphasises social and economic impacts, although these dimensions receive comparatively less attention. From a social perspective, environmental degradation and ecosystem disturbances can reduce the adaptive capacity of coastal communities to climate-related pressures such as sea-level rise, increasing the vulnerability of settlements and livelihoods (Spanier & Kuenzer, 2024; Yuan et al., 2023). Economically, cumulative environmental degradation, including overexploitation of fisheries, depletion of marine resources, and pollution from untreated discharges, can negatively affect food security and local economies reliant on marine resources within MSES (Kuşku et al., 2018; Yuan et al., 2023). In addition, infrastructure failures and ecosystem degradation may lead to economic losses for coastal communities dependent on fisheries, tourism, and other marine-based industries (Ware & Callaway, 2019). Overall, the literature demonstrates that the negative impacts of maritime infrastructure on MSES are multidimensional, encompassing environmental, social, and economic dimensions. However, the synthesis indicates that existing studies predominantly focus on environmental impacts. In contrast, social and economic consequences are comparatively less explored, despite their critical implications for coastal livelihoods and long-term socio-ecological resilience. This collectively emphasise the need for holistic and integrated approaches to mitigate negative impacts while enhancing positive impacts.

Notably, maritime infrastructure generates simultaneous trade-offs and synergies across ecological, social, and economic dimensions. For instance, offshore renewable energy infrastructure and coastal defence structures may enhance coastal protection, renewable energy generation, and economic development, while simultaneously contributing to habitat fragmentation, altered hydrodynamics, and social vulnerability within coastal communities. These interactions reflect the interconnected and dynamic nature of MSES, where ecological and social systems continuously influence one another through feedback mechanisms, adaptive processes, and governance structures. The review further emphasises that the balance between benefits and adverse impacts is highly context-dependent and influenced by factors including infrastructure type, scale, geographical location, ecological sensitivity, governance effectiveness, stakeholder participation, and the extent of nature-inclusive design integration.

5. CONCLUSIONS AND FUTURE DIRECTIONS

This study aimed to examine the impacts of maritime infrastructure on MSES through a narrative review approach. The findings demonstrate that maritime infrastructure generates complex and interconnected environmental, social, and economic impacts across both ecological and social systems. While maritime infrastructure contributes positively to renewable energy generation, coastal protection, maritime connectivity, fisheries productivity, and regional economic development, it simultaneously creates substantial challenges including habitat degradation, ecological fragmentation, biodiversity disturbance, pollution, and increased socio-economic vulnerability within coastal communities. These findings emphasise maritime infrastructure as an integral component of dynamic MSES characterised by continuous interactions, trade-offs, and feedback between human and ecological systems. The study further highlights that the impacts of maritime infrastructure are highly context-dependent and influenced by infrastructure type, spatial scale, governance arrangements, ecological sensitivity, and the extent of nature-inclusive design integration. The implications of this study extend across multiple domains. From a theoretical perspective, this study contributes to the existing MSES literature by synthesising fragmented knowledge on maritime infrastructure impacts into a structured approach encompassing ecological and social systems, positive and negative impacts, and environmental, social, and economic dimensions. For society, the study illustrates the direct links between maritime infrastructure, coastal ecosystem services, and community well-being, emphasising the importance of participatory governance and sustainable ocean management to ensure equitable benefits and minimise adverse impacts. For industry, the findings highlight the need for ecologically informed infrastructure design and operational strategies, including eco-engineered structures, cumulative impact assessments, and integration of renewable energy, to enhance economic productivity while reducing ecological harm. Future research is recommended to adopt in-depth case study approaches to comprehensively examine the socio-economic dimensions of maritime infrastructure within MSES through the integration of economic models such as the blue economy, thereby supporting sustainable ocean management. Future research should prioritise identifying the underlying drivers and root causes of both positive and negative impacts of maritime infrastructure on MSES, thereby enabling the development of more innovative, sustainable, and nature-based design solutions that minimise ecological and social disruptions. This study has several limitations, primarily due to its reliance on a literature review, which may overlook recent research or unpublished studies, potentially resulting in an incomplete understanding of maritime infrastructure impacts. Furthermore, the selection of search terms and literature sources may influence the findings, limiting their generalisability. Despite these limitations, this study provides a comprehensive benchmark for future in-depth research and contributes to advancing knowledge on sustainable maritime infrastructure development within MSES.

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