

The Impact of Coastal Livestock Activities on the Health of Dugong (*Dugong dugon*) Habitats: A One Health Approach in Tropical Regions

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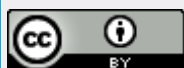
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Abstract

The *Dugong dugon* a vulnerable marine herbivore, is closely tied to the health of seagrass ecosystems, which are increasingly threatened by land-based livestock activities in tropical coastal areas. This review explores how nutrient runoff, heavy metal contamination, and microplastics "primarily from livestock farming" contribute to eutrophication, biodiversity loss, and degradation of dugong forage quality. Moreover, the proximity of livestock to marine environments raises risks of zoonotic disease transmission, physiological stress, and mortality in dugongs. Using a One Health framework, this article highlights the ecological and health implications of terrestrial-marine interactions and identifies gaps in research and policy. Recommendations include integrated monitoring, sustainable livestock management, and transdisciplinary collaboration to protect dugong populations and their habitats.

Abstrak

Kelangsungan hidup dugong (*Dugong dugon*), herbivora laut yang rentan, berkaitan erat dengan kesehatan ekosistem lamun, yang semakin terancam oleh aktivitas peternakan berbasis darat di wilayah pesisir tropis. Tinjauan ini mengeksplorasi bagaimana limpasan nutrisi, kontaminasi logam berat, dan mikroplastik "terutama dari peternakan" berkontribusi terhadap eutrofikasi, hilangnya keanekaragaman hayati, dan degradasi kualitas hijauan dugong. Lebih lanjut, kedekatan ternak dengan lingkungan laut meningkatkan risiko penularan penyakit zoonosis, stres fisiologis, dan mortalitas pada dugong. Dengan menggunakan kerangka kerja One Health, artikel ini menyoroti implikasi ekologis dan kesehatan dari interaksi darat-laut dan mengidentifikasi kesenjangan dalam penelitian dan kebijakan. Rekomendasi mencakup pemantauan terpadu, pengelolaan ternak berkelanjutan, dan kolaborasi transdisipliner untuk melindungi populasi dugong dan habitatnya.

INTRODUCTION

Seagrass ecosystems are recognized as vital coastal habitats that provide essential ecological services, such as supporting marine biodiversity, stabilizing sediments, and improving water quality (Herrera et al., 2022; Ugarelli et al., 2018). It is well established that these ecosystems are critical for the survival of the dugong (*Dugong dugon*), a vulnerable marine mammal that depends almost exclusively on seagrass as its food source (Karlina et al., 2018; Thibault et al., 2024). Existing studies have documented the ecological role of dugongs as ecosystem engineers, where their foraging behavior influences seagrass biomass, species composition, and overall meadow health (Heng et al., 2022; Marsh & Kwan, 2008). Their presence and population status are widely used as indicators of seagrass ecosystem health (Cullen-Unsworth et al., 2018; Meidina et al., 2023).

However, despite this established knowledge, several knowledge gaps remain. First, while global and regional studies have highlighted dugong declines due to seagrass degradation (Moore et al., 2017; Coles et al., 2018), there is still limited understanding of the specific pathways through which land-based livestock activities contribute to seagrass decline and dugong population stress, particularly in tropical regions. Second, much of the existing literature has been conducted in Australia and the Pacific, whereas empirical data from Southeast Asia, including Indonesia, are comparatively scarce, despite this region being a

critical habitat for dugongs. Third, although dugongs are recognized as keystone species, there is insufficient synthesis on how their decline feeds back into seagrass ecosystem resilience under increasing anthropogenic pressures.

This review therefore focuses on the Southeast Asian context, with particular emphasis on Indonesia as one of the last strongholds of dugong populations. Specifically, it aims to (i) synthesize existing knowledge on dugong–seagrass interactions, (ii) critically evaluate how livestock and land-based agricultural activities impact seagrass ecosystems and dugong health, and (iii) identify research gaps and management challenges to support integrated conservation strategies. By clarifying what is known and unknown, this review seeks to provide a more regionally grounded and actionable perspective on dugong conservation within the broader framework of land sea interactions.

METHODS

This study employed a systematic literature review (SLR) approach based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological transparency, reproducibility, and rigor. The Scopus database was selected as the primary source of literature due to its wide coverage of peer-reviewed scientific journals in the fields of environmental science, veterinary medicine, marine biology, and interdisciplinary health.

A structured search strategy was developed using a combination of keywords and Boolean operators, including: “*dugong*” OR “*Dugong dugon*”, “*seagrass*” AND “*habitat degradation*”, “*coastal livestock*” OR “*agricultural runoff*”, “*One Health*” AND “*marine mammals*”, and “*tropical regions*” OR “*Southeast Asia*”. In addition to the initial database search, forward and backward citation tracking was performed to identify additional relevant publications that may not have appeared in the primary search results. Inclusion criteria were established to ensure the quality and relevance of selected literature. Articles had to be published in Scopus-indexed journals, written in English, and focus on topics including dugong ecology, seagrass ecosystem health, the environmental impact of livestock or agriculture near coastal areas, marine pollution, and/or the application of One Health principles. Only studies published between 2005 and 2025 were considered eligible.

Editorials, commentaries, and non-peer-reviewed materials were excluded from the analysis. The choice of the 2005–2025 publication range was based on several considerations. First, the past two decades have marked significant advancements in scientific understanding of land-sea interactions, marine ecosystem degradation, and the application of One Health frameworks in wildlife conservation. Second, this period reflects a growing global concern over climate change, eutrophication, and zoonotic diseases, particularly in coastal and tropical regions. Third, conservation initiatives such as marine protected areas (MPAs), community-based habitat protection, and integrated coastal zone management became more prominent after 2005, making literature from this era more relevant to the study’s aims. Lastly, recent years have seen a surge in research addressing disease emergence at the human-animal-environment interface key to a One Health approach.

The initial Scopus search yielded a total of 344 articles. After title and abstract screening, 123 articles were selected for full-text review. Following the application of the inclusion and exclusion criteria, a final set of 60 articles was included in the review. From each selected article, the following data were extracted: authors and publication year, geographical focus, research objectives, methodologies employed, key findings related to dugong health and seagrass degradation, and any proposed conservation or management recommendations.

The extracted data were then thematically analyzed and synthesized into four major domains: (1) characteristics of coastal livestock practices in tropical regions, (2) impacts of anthropogenic activities particularly nutrient runoff and pollution on seagrass ecosystems, (3) health risks to dugongs arising from livestock-associated environmental degradation, and (4) the application of One Health strategies to support dugong conservation. Both qualitative insights and quantitative outcomes (where available) were used to develop a comprehensive

understanding of the interconnected challenges facing dugong habitats and to identify pathways for integrated and cross-sectoral management solutions.

RESULT AND DISCUSSION

Characteristics of Coastal Livestock Practices in Tropical Regions

Coastal livestock farming in Southeast Asia is diverse, encompassing poultry, pigs, and swamp buffaloes, often integrated with rice farming and aquaculture to optimize resource use (Tiemann & Douxchamps, 2023; Wanapat et al., 2010). These complex farming systems are central to food security and rural livelihoods, with animals such as swamp buffaloes serving multiple functions including meat, manure, and draught power (Wanapat et al., 2010). However, inadequate waste management remains a persistent issue, with nutrient-rich effluents from livestock frequently entering coastal waters. This runoff contributes to eutrophication, harmful algal blooms, and the degradation of water quality (Rangel-Buitrago et al., 2024; Sampat et al., 2021). The problem is particularly acute in Southeast Asia, where high livestock density near coasts amplifies the risk of nutrient leakage into marine ecosystems (Shimizu et al., 2013). Despite existing recommendations, effective waste management practices are inconsistently implemented and poorly enforced (Burkholder et al., 2007; Liu & Zeng, 2024).

While it is broadly recognized that coastal livestock activities can degrade marine habitats, several research gaps remain unaddressed. First, there is a lack of quantitative studies directly measuring the impacts of coastal pig farming effluents on seagrass quality and productivity, despite strong anecdotal links between nutrient enrichment and seagrass decline. Second, spatially explicit models that link livestock waste hotspots with dugong distribution are largely absent, limiting our ability to predict overlap between pollution sources and critical dugong habitats. Third, comparative studies across different livestock types (e.g., pigs, poultry, buffalo) are scarce, making it difficult to determine which farming systems exert the greatest ecological pressure on coastal waters. Finally, there is limited exploration of threshold levels of nutrient runoff that seagrass ecosystems and dugong populations can tolerate in tropical settings. Addressing these gaps is critical for developing integrated land–sea management strategies. Future research should prioritize empirical field measurements, spatial modeling, and comparative system analyses to better understand and mitigate the cumulative impacts of coastal livestock farming on seagrass ecosystems and dugong conservation in Southeast Asia.

Impacts on Seagrass Ecosystem Health

Eutrophication, primarily driven by anthropogenic activities such as agriculture and aquaculture, significantly impacts seagrass ecosystems by increasing nutrient loads, triggering algal blooms, and reducing light penetration and oxygen availability (Komita et al., 2024; Long & Mora, 2023; Neverova-Dziopak, 2018). The decomposition of algal biomass generates hypoxia and anoxia, which in turn disrupt seagrass photosynthesis and root respiration (Dorgham, 2013; Scavia & Bricker, 2006). Beyond these direct effects, eutrophication alters nutrient cycling and promotes the dominance of cyanobacteria, reducing biodiversity and ecosystem stability (Sarma & Kumar, 2024). While chronic aquaculture effluents have been linked to up to an 87% decline in seagrass biomass (Thomsen et al., 2020), comparative studies across regions remain scarce, leaving uncertainty about how local hydrodynamics and species composition mediate resilience.

Heavy metals and microplastics present additional stressors. Cadmium, lead, and other metals accumulate in seagrass tissues, disrupting enzymatic activity and inducing oxidative stress (Arunakumara & Zhang, 2008; Sharma & Kumari, 2023). Microplastics exacerbate these impacts by acting as vectors for heavy metals and by physically obstructing light and nutrient transfer (Narwal et al., 2024; Tang, 2024). Experimental work shows that combined exposure increases pollutant bioaccumulation and alters sediment microbial communities, thereby modifying biogeochemical cycles (Gerstenbacher et al., 2022; Cong et al., 2025). However, most studies are site-specific and short-term, with limited evidence on the cumulative and long-term impacts at ecosystem or regional scales. The ecological implications extend to higher trophic levels, particularly dugongs, which depend on seagrass as their primary food source. Dugongs

show a preference for pioneer species such as *Halophila ovalis*, which are more responsive to nutrient enrichment but also more vulnerable to sudden collapse (Yamamuro & Chirapart, 2005). Pollution-driven shifts in seagrass nutrient composition may reduce forage quality and exacerbate dugong vulnerability, especially given their limited ability to process fibrous seagrass (Marsh et al., 2018). Despite this, there remains a paucity of quantitative studies directly linking eutrophication or pollution levels to dugong foraging behavior, health, and population dynamics in tropical regions.

Restoration and management interventions such as nutrient load reduction, seagrass transplantation, and integrated coastal management have been attempted (Cardoso et al., 2008), yet discussion in the literature remains general, with few actionable guidelines tailored for Southeast Asia. Moreover, extreme events such as storms and marine heatwaves frequently undermine restoration success, highlighting the need for adaptive, climate-informed strategies. Overall, while existing research establishes clear connections between eutrophication, pollutants, and seagrass decline, the literature remains largely descriptive, with insufficient synthesis of ecological and biogeochemical mechanisms, spatial temporal variability, and interspecies responses. The role of dugongs as both indicators and beneficiaries of seagrass health is often underexplored, weakening the ecological framing of conservation arguments. Future studies should integrate quantitative, long-term monitoring, cross-species comparisons, and ecosystem modeling to close critical knowledge gaps and support more concrete recommendations for restoration and management in tropical coastal systems. More concise information can be found in Table 1.

These impacts highlight the need for comprehensive management strategies to mitigate eutrophication, control pollution, and protect seagrass ecosystems to ensure the health and sustainability of these vital habitats.

Table 1. Main Ecological Consequences of Eutrophication and Contaminants on Seagrass and Dugong Forage in Tropical Coastal Zones

Impact	Description	Supporting Abstracts
Eutrophication	Reduces water clarity, oxygen levels, shifts phytoplankton communities, causes hypoxia/anoxia, and declines in seagrass biomass and species diversity.	(Cardoso et al., 2008; Dorgham, 2013; Komita et al., 2024; Long & Mora, 2023; Neverova-Dziopak, 2018; Sarma & Kumar, 2024; Scavia & Bricker, 2006; Thomsen et al., 2020)
Heavy Metals and Microplastics	Bioaccumulation in seagrass tissues, oxidative stress, reduced photosynthetic efficiency, altered nutrient cycling, and harm to sediment communities.	(Arunakumara & Zhang, 2008; Cong et al., 2025; Gerstenbacher et al., 2022; Narwal et al., 2024; Pasumpon & Vasudevan, 2021; Sharma & Kumari, 2023; Tang, 2024; L. Wang et al., 2021)
Dugong Forage	Preference for faster-growing seagrass species, impact of eutrophication and pollution on nutrient composition, reduced nutritional value and availability, and vulnerability during seagrass loss.	(Marsh et al., 2018; Yamamuro & Chirapart, 2005)

Health Risks to Dugongs Related to Livestock Activities

Dugongs may face potential risks of zoonotic exposure due to the increasing interaction between coastal livestock farming and marine ecosystems, but direct empirical evidence remains limited. While the expansion of livestock farming and its interface with ecotourism and fishing activities could theoretically increase the likelihood of pathogen spillover, claims about dugong-specific vulnerability should be made cautiously to avoid overgeneralization (Bekker et

al., 2012). Zoonotic pathogens such as tuberculosis, brucellosis, and leptospirosis have been documented in livestock systems (Alemayehu et al., 2024; LeJeune & Kersting, 2010), yet confirmed transmission routes to dugongs are not well established. Post-mortem examinations in southeast Queensland reported dugong deaths linked to infections and chronic conditions potentially associated with environmental stressors, but causal links with livestock-derived pathogens remain uncertain (Owen et al., 2012).

A critical research gap lies in understanding the ecological pathways through which livestock activities may influence dugong health. Possible transmission mechanisms include nutrient-driven eutrophication that alters seagrass quality, microbial contamination of coastal waters, or indirect stress via habitat fragmentation and increased human presence (Richter et al., 2015; Maitland et al., 2006). However, localized ecological contexts such as differences in coastal hydrodynamics, livestock management practices, and dugong feeding behavior likely mediate these risks, and such nuances are rarely addressed in existing studies. Strengthening empirical evidence through targeted case studies, including pathology and disease surveillance in dugong populations within livestock-dense coastal regions, is essential to clarify these pathways. Without this, the broader ecological and epidemiological implications of livestock–dugong interactions remain speculative and represent a key frontier for future One Health-oriented research. More concise information can be found in Table 2.

Table 1. Dugong Morbidity and Mortality Factors Attributed to Livestock-Influenced Coastal Environments		
Health Risk	Details	Supporting Abstracts
Exposure to Zoonotic Pathogens	Increased interaction between livestock and wildlife raises the risk of zoonotic disease transmission to dugongs.	(Alemayehu et al., 2024; Bekker et al., 2012; LeJeune & Kersting, 2010)
Physiological Stress and Habitat Fragmentation	Agricultural intensification and habitat fragmentation lead to environmental contamination and increased stress for dugongs.	(Maitland et al., 2006; Richter et al., 2015)
Post-mortem Findings	Human activities, including those related to livestock, are significant causes of dugong mortality, with infections and chronic debility observed.	(Owen et al., 2012)

Livestock activities pose several health risks to dugongs, including exposure to zoonotic pathogens, physiological stress due to habitat fragmentation, and increased mortality from pollution-related diseases. These findings underscore the need for integrated management strategies to mitigate the impact of livestock farming on dugong populations.

One Health Strategies for Dugong Conservation

The One Health approach emphasizes the interconnectedness of human, animal, and environmental health, which is crucial for dugong conservation. This approach can help address the multifaceted threats to dugongs, such as habitat degradation, incidental catch in fishing nets, and climate change impacts on seagrass beds (Hines et al., 2005; Moresco et al., 2022; B. Wang et al., 2025). However, current discussions remain mostly descriptive, with limited quantitative evidence such as measured nutrient runoff loads from livestock areas or recorded dugong health indicators that could strengthen the argument for One Health applicability in practice. Monitoring the health of dugong populations through systematic health assessments and disease surveillance can indeed provide insights into marine ecosystem health (Grattarola et al., 2024; Lanyon et al., 2010; Wund et al., 2023), yet few studies evaluate these methods with rigorous numerical or epidemiological data.

Another gap lies in the lack of distinction between the conceptual framework of One Health

and its on-the-ground implementation. While One Health is portrayed as a unifying paradigm, case studies from Indonesia (e.g., Pokmaswas initiatives) differ significantly from more formalized surveillance in countries such as Australia, but comparative analyses are scarce (Amany et al., 2022). Similarly, the advantages of this approach are highlighted, but limitations including institutional fragmentation, high costs of integrated monitoring, and enforcement challenges are rarely critiqued. Sustainable livestock practices near MPAs are frequently suggested to minimize runoff (Grech & Marsh, 2008), yet concrete evaluations of regulatory instruments or local enforcement remain limited.

The socio-economic context of coastal communities, including livelihood dependence on fisheries and livestock, conflicts over marine space, and household vulnerabilities to conservation restrictions, is only superficially discussed. Community-based interventions, such as those implemented in Tolitoli Regency, Indonesia (Amany et al., 2022), show potential, but more detailed assessments of their economic trade-offs are needed. Policy recommendations, including establishing MPAs, promoting sustainable fishing, and reducing habitat destruction (Hines et al., 2008), remain general and normative, without a deeper exploration of relevant regulations, such as Indonesia's national fisheries law or ASEAN regional frameworks. Future research should therefore integrate quantitative assessments, clarify the divide between One Health theory and practice, critically examine barriers to implementation, and situate dugong conservation within both global examples and local socio-economic realities. This would prevent overgeneralization and make One Health more actionable for dugong and seagrass conservation.

CONCLUSION

Coastal livestock activities significantly impact dugong habitats through eutrophication, contamination by heavy metals and microplastics, and habitat fragmentation. These stressors degrade seagrass ecosystems, the primary food source for dugongs, reducing its quality, availability, and nutritional value. Dugongs are further exposed to health risks such as zoonotic diseases and physiological stress due to land-based pollution and environmental disturbances. Despite growing concern, direct studies linking livestock practices and dugong health remain limited. Current research often overlooks livestock-specific impacts and lacks long-term ecological and health monitoring. Future research should focus on mapping land-sea interactions, tracking pollutant effects on dugong physiology, and exploring pathogen transmission at the livestock-marine interface. Integrating the One Health approach into coastal policy and conservation planning is essential. Sustainable livestock practices, better waste management, and strengthened marine protection can help reduce pressures on dugongs and promote ecosystem health in tropical coastal areas.

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